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Evaluation of the Use of a Bedleveler to Improve Navigability of Atchafalaya River Bar Channel Fluid Mud

Michael Tubman, Timothy Welp, Mike Sullivan, and Chris Colombo

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Abstract

Between routine navigation dredging operations, the Atchafalaya River Bar Channel (ABC) traps fluid mud, which begins to consolidate. The consolidated mud can begin to block the passage of vessels using the Port of Morgan City, LA. If the mud densities and yield stresses could be kept sufficiently low so that vessels could safely navigate through it, the length of time between navigation dredging could potentially be increased. To demonstrate the feasibility of dragging a large object through the mud to condition the sediments, a bedleveler was constructed and suspended below a barge at depths that penetrated the interface between the water and the fluid mud in the channel (i.e., the lutocline). The barge was towed along the ABC parallel to its axis, thereby dragging the bedleveler through the fluid mud on the channel bottom.

It was found that dragging the bedleveler along the channel seemed to have no effect, or an extremely limited effect, over a short duration on the densities. It cannot be ruled out that the bedleveler operations had an effect on yield stresses, but the measured decreases were so inconsistent that naturally occurring changes or other factors had a larger effect.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE) under the Dredging Operations and Environmental Research (DOER) Program work unit 456009“Corps Implementation of Nautical Depth.” The USACE Doer Program Manager was Dr. Todd Bridges, Engineer Research and Development Center (ERDC) Environmental Laboratory (EL). At the time this study was conducted, Mr. Jeffrey A. McKee was the USACE Navigation Business Line Manager overseeing the DOER Program. Mr. W. Jeff Lillycrop, ERDC Coastal and Hydraulics Laboratory (CHL), was the Technical Director for Civil Works and Navigation Research, Development, and Technology Transfer (RD&T) portfolio.

The work was performed by the Coastal Engineering Branch (CEERD-HN-C) of the Navigation Division (CEERD-HN) of ERDC CHL. Ms. Tanya Beck was Chief, CEERD-HN-C, and Dr. Jackie Pettway was Chief, CEERD-HN. At the time of this study, Dr. William Martin was Director, ERDC CHL, and Mr. José E. Sánchez was Deputy Director, CHL.

This study documents a monitoring/testing effort at the Atchafalaya Bar Channel to implement the nautical depth concept by USACE in conjunction with the Port of Morgan City, LA. This effort was supported by the USACE New Orleans District (MVN) and by the Port of Morgan City. Appreciation is extended to MVN personnel Ms. Sarah Nash and Mr. Mike Lowe, Project Managers; Mr. Chris Colombo, Chief of Hydrographic Survey; and Mr. Mike Sullivan, Chief Hydrographer; in cooperation with Moffat & Nichol Engineers representing the Port of Morgan City (Dr. Robert Engler, Mr. Jonathon Hird, and Mr. Maarten Kluijver). Appreciation is also extended to Weeks Marine, Inc., Cranford, NJ, for their cooperation and use of their bedleveler in the execution of these bedleveling operations at the Atchafalaya River Bar Channel.

At the time of publication, the ERDC CHL Director was Mr. José E. Sánchez, and the CHL Deputy Director was Mr. Jeffrey R. Eckstein. Commander of ERDC was COL Bryan S. Green, and the Director of ERDC was Dr. David. W. Pittman.

Unit Conversion Factors

Non-SI units of measurement in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles per hour	0.44704	meters per second
pound-mass per cubic foot	16.0185	grams per cubic centimeter
pound-force per square inch	47.8803	Pascals

Grams per cubic centimeter (g/cm^3) can be converted to grams per liter (g/L) by multiplying by 1000.

1 Introduction

Background

The Atchafalaya River Bar Channel (ABC) is part of a congressionally authorized navigation route that serves the Port of Morgan City, LA, and is maintained by the U.S. Army Corps of Engineers (USACE) New Orleans District (MVN). It is approximately 16 miles long and 400 feet (ft) wide with a depth of -20 ft Mean Low Gulf (MLG), including an additional 2 ft advanced maintenance and 2 ft allowable overdepth. Between routine navigation dredging operations, the channel traps fluid mud, which consolidates over time. The consolidated mud can begin to block the passage of vessels using the Port. If the mud densities and yield stresses could be kept sufficiently low so that vessels could safely navigate through it, the length of time between navigation dredging could potentially be increased. In addition, if the means of doing this could be quickly and easily implemented, emergency situations where a short length of channel posed a risk to navigation could be dealt with expediently.

Mud densities of approximately 1.2 to 1.3 grams per cubic centimeter (g/cm^3) and yield strengths of 50 to 70 Pascals (Pa) have been accepted at ports as being navigable (Wurpts and Greiser 2007). In situ conditioning of sediments can break inter-floc bonds and lower densities and yield strengths. As practiced in Europe, this is accomplished by agitating the fluid mud with a hopper dredge. A simpler and less expensive method of agitating the fluid mud that could potentially have the same result is to stir the mud by dragging a large object through it.

Objective

The objective of this project was to demonstrate the feasibility of this method to improve navigability in the ABC, a 70,000 pound (lb), 50 ft wide, 3 ft × 3 ft beam (commonly referred to as a bedleveler) was constructed and suspended below a barge at depths that penetrated the interface between the water and the fluid mud in the channel (i.e., the lutocline). The barge was towed along the ABC parallel to its axis, thereby dragging the bedleveler through the fluid mud on the channel bottom.

Approach

A Stema Systems survey system consisting of two primary components, a Rheotune and the SILAS, was used to measure fluid mud properties before and after the bedleveler was towed through the fluid mud. The Rheotune is a profiling instrument lowered into the fluid mud from a survey vessel and measures the density and yield stress of the fluid mud. SILAS is a software system with acoustic subbottom reflection signal (in the low-frequency range of 3.5 to 33 kiloHertz [kHz]) acquisition and processing modules. The low-frequency acoustic returns are processed to determine signal attenuation and calibrated for density using the density profiles collected with the Rheotune. This report presents the procedures, measurements, data analysis, and results from the demonstration.

Multiple before- and after-drag Rheotune density and yield stress profiles at fixed stations along the length of the ABC where the bedleveler was dragged were measured and compared by various methods. In the first comparison, the errors in the profile data were determined to be entirely random and were treated as such. The mean before-drag densities and yield stresses at 1 ft depth intervals were compared to the after-drag means, and the statistical significance of the differences was calculated using a z-test. The second comparison used a subjective method of eliminating entire profiles if they appeared to be shifted. After removing the profiles that appeared to be shifted, the before-and-after means at each 1 ft interval were compared without evaluating the statistical significance of the differences.

SILAS density horizons were also analyzed and plotted to evaluate acoustically measured density values of the before- and after-drag conditions. Plots of the depths of the 1.300 g/cm^3 and 1.250 g/cm^3 fluid mud densities along the full length of the ABC where the bedleveler was dragged (i.e., the 1.300 g/cm^3 and 1.250 g/cm^3 horizons) were plotted for a survey before any bedleveler drag operations were conducted and for a survey immediately after all bedleveler operations were complete. These plots were examined to determine if there were any consistent, visually obvious differences between the horizons that could be attributed to the drag operations.

2 Test Location and Procedures

Demonstration area

Figure 1 shows the demonstration area in the Gulf of Mexico near the entrance to Atchafalaya Bay and the Atchafalaya River. The area is in the ABC, the navigation route serving Morgan City, LA, located approximately 28 miles north of the ABC. The ABC reach selected for the demonstration was originally between Stations 780 and 808, but during the evolution of the demonstration, it was extended to include two additional reaches between Stations 820 and 832 and between Stations 756 and 768 (Figure 1). The added reaches provided test sections for two additional tow depths. The tow depths were chosen to target depths covered by the 3 ft high bedleveler where bottom properties fluctuated about the lutocline (-19 ft), the 1.250-1.300 g/cm^3 density layer (-21 ft), and the 50 Pa yield-stress layer (-22 ft). The ABC test sections, tow depths of the bottom of the bedleveler, and drag dates are listed in Table 1.

Bedleveler and operations

Bedlevelers, drag beams, and similar devices work by being pulled over the bottom (usually suspended from a vessel by cables or chains), mechanically loosening and *dragging* the bottom material, and raising it into the water column to be carried away by natural currents. Bedlevelers, while attaining some agitation dredging, are used primarily to reduce the height of bottom material by *knocking down* or redistributing this material into deeper locations.

Typical bedleveler towing speeds range from 1 to 2 knots. Bedlevelers are used more often in soft sediment maintenance materials and substrate that has never been previously dredged (new work), clay, and even small pieces of rock but are used much less often in sand. The number of passes required depends entirely on the type of material being moved, the height of the ridge to be leveled, and the weight of the bedleveler (USACE 2015).

Figure 1. ABC demonstration area with station numbers and Rheotune profile locations (red dots).

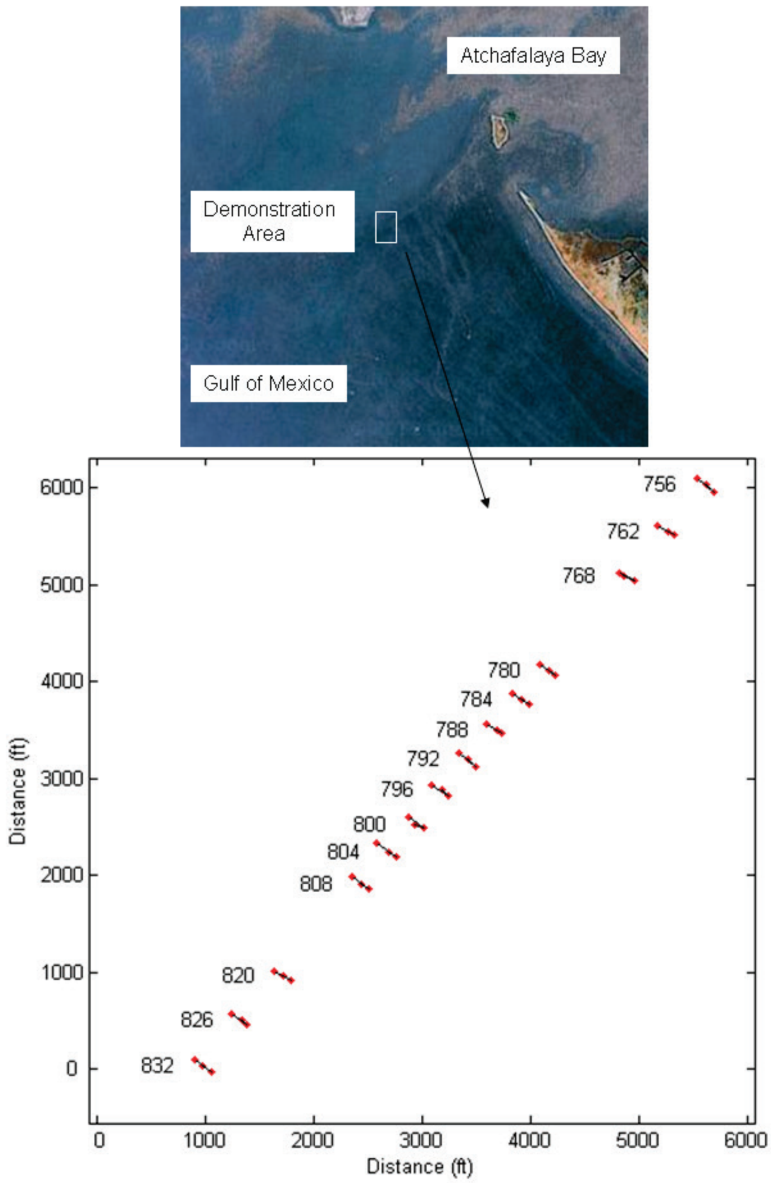


Table 1. ABC test sections, stations, drag depths, and drag dates.

Test Sections	Stations Dragged	Depth of Bedleveler (ft)	Drag Date(s)
1	780 - 808	-21	11/30/11
2	820 - 832	-22	11/20/11
3	756 - 768	-19	12/2/11 to 12/4/11

The 70,000 lb (35 ton), 50 ft wide, 3 ft × 3 ft bed leveler (Figure 2) was provided by Weeks Marine, Inc. under a rental contract. The pushtug *Charlie G.* (1,800 horsepower) (Figure 3) was used to propel the plow barge (*WEEKS 12*) with the bedleveler suspended beneath it. This barge was originally pushed by the *Charlie G.*, but during initial testing the bedleveler suspension cables were swinging back too far aft to operate efficiently, so the plow barge was towed (as shown in Figure 3) at speeds that ranged (depending on bedleveler depth) from 1.4 to 2.5 miles per hour.

Figure 2. Weeks Marine Inc. bedleveler.

Figure 3. Pushtug *Charlie G.* towing the plow barge (*WEEKS 12*).

The greater density and yield stress at the bedleveler tow depth, the slower the bedleveler had to be towed. For each setup, the bedleveler was dragged longitudinally along the reach at the designated depth (defined as a run) until the entire width of the channel was dragged (designated as a pass). Four passes were made over each of the three reaches to enhance modification of the properties of the fluid mud. The contractor used a Global Positioning System (GPS) to ensure that the bedleveler was pulled on the intended paths and to ensure that overlaps between adjacent runs were completed. Bedleveler depth was measured manually via graduated paint marks on the suspension wire ropes. The contractor had graduated marks painted on the deck by each winch to verify the accuracy of the marks on the wire ropes. Starting with zero being the place where the bottom of the bedleveler touched the water, the cables were painted in 5.0 ft increments up to 20.0 ft and 1.0 ft increments from 20.0 to 25.0 ft. The demonstration began on 30 November 2011 and concluded 4 December 2011. Including downtime and standby time, this resulted in a total dragging time of 72 hours (hr).

Channel fluid mud surveying

Fluid mud physical characteristics were surveyed by MVN personnel with the Stema system onboard the MVN survey vessel *TECHE*. The Stema system consists of two primary components, a Rheotune and the SILAS. The Rheotune is a fluid mud profiling probe that operates on the *tuning fork* principle, with one of the legs of the tuning fork vibrating at a specific frequency and the other leg vibrating at a frequency and amplitude that depend on the density and rheological properties of the medium in which the probe is inserted. The natural resonant frequency of the vibrating fork sensor decreases as the density of the fluid mud increases, and the amplitude of vibrations decrease with increasing viscosity. Thus, measurements of the frequency and amplitude of the vibrating sensor are processed by the Rheotune and result in independent measurements of density and viscosity. In general, the tuning-fork method of measuring density and viscosity is restricted to Newtonian fluids, which continue to flow even when very small forces act on them. Fluid muds of interest in navigation studies generally show non-Newtonian behavior. However, they are enough like a Newtonian fluid that the non-Newtonian behavior can be accounted for by using a proprietary calibration developed by Stema. The Rheotune uses a predefined generalized density calibration based on database values from worldwide natural mud materials. Site-specific conditions may require modifying the density calibration.

The yield stress is defined as the stress applied to the mud that is needed to initiate flow. The vibrations of the tuning fork do not impart enough force on typical muds of navigation interest to produce this effect. However, Stema found that the amplitude damping effect could be correlated with yield stress. The amplitude damping effect caused by the viscous behavior of the mud appears from their studies to be uniform in muds of navigation interest. Stema created a database that compares the viscous damping of their tuning fork sensor amplitudes with yield-stress values (measured with a Brookfield viscometer) in muds spanning the range of those of navigation interest. The results of these comparisons are incorporated in the Rheotune calibration, and the Rheotune outputs yield-stress values from its viscosity measurements.

To check the Rheotune's density calibration for the fluid mud present in the ABC, fluid mud was collected from the channel by Ponar grab sampler and placed in a 5 gallon bucket. The Rheotune probe's tuning fork was immersed in the mud and made density measurements. Additional channel water was then added to the bucket, and the mixture was homogenized by stirring to create a less dense suspension. This was done a second time, resulting in measurements of three different densities. Samples were collected from each of these trials and analyzed with a pycnometer for bulk density at the U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) and compared with the Rheotune measurements. The comparison results (listed in Table 2) show reasonable expected differences between Rheotune and lab-measured samples for the low, medium, and dense suspensions (0.010 g/cm^3, -0.021 g/cm^3, and -0.013 g/cm^3, respectively).

Table 2. Comparison between Rheotune and laboratory-measured densities.

Mixture	Rheotune Density (g/cm^3)	Standard deviation (g/cm^3)	Laboratory Density (g/cm^3)	Standard deviation (g/cm^3)	Difference (g/cm^3)	Relative Difference Percent (%)
Most Dense	1.280	0.0077	1.270	0.010	0.010	0.78
Medium Dense	1.215	0.002	1.236	0.021	-0.021	1.69
Least Dense	1.194	0.002	1.207	0.024	-0.013	1.07

The Rheotune was lowered from the workboat *TECHE* by a semiautomated winch into the channel (Figure 4) to measure and record water and fluid mud densities and yield stresses as a function of depth. Figure 5 presents examples of the survey systems density vs. depth and yield stress vs. depth profiles at Station 756.

The SILAS software was developed for the acquisition and processing of acoustic subbottom reflection signals in the low-frequency range of 3.5 to 33 kHz. The low-frequency acoustic returns are processed to determine signal attenuation and calibrated for density with the density profiles collected with the Rheotune. SILAS transects were run along the centerline of the channel by the *TECHE*. An example of SILAS output for the 1.250 g/cm^3 horizon is shown in Figure 6.

Figure 4. Rheotune probe being deployed off the *TECHE* via a semiautomated winch.

Figure 5. Rheotune density vs. depth (a) and yield stress vs. depth (b) profiles.

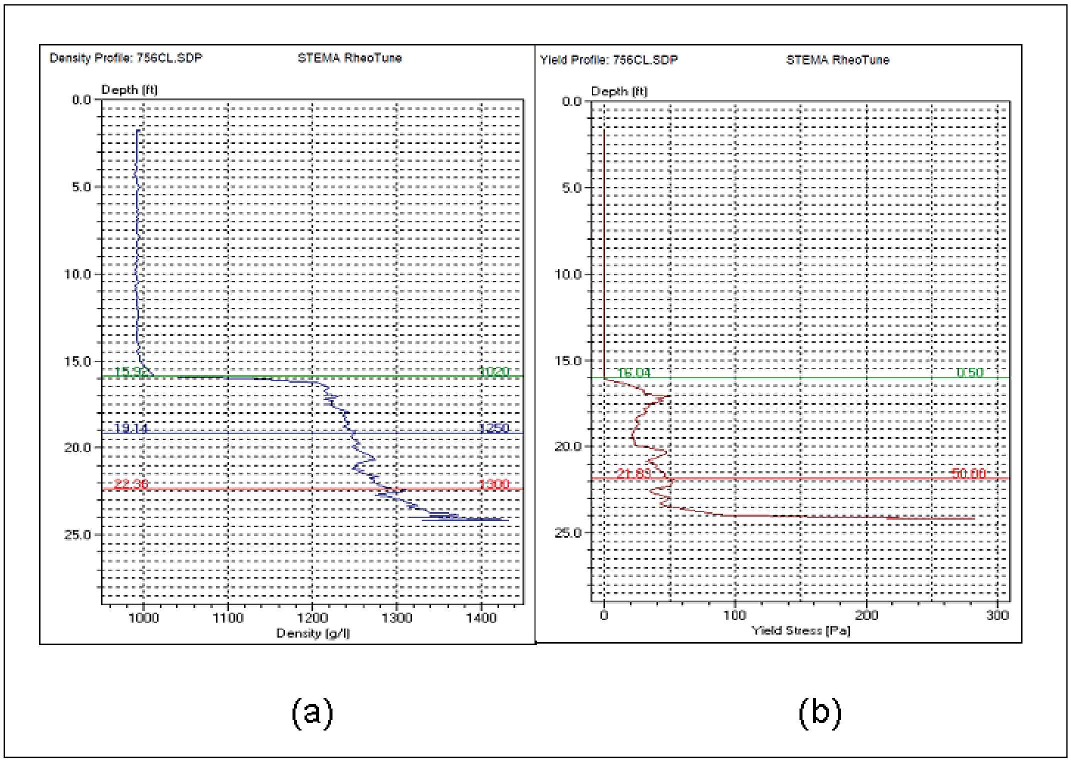
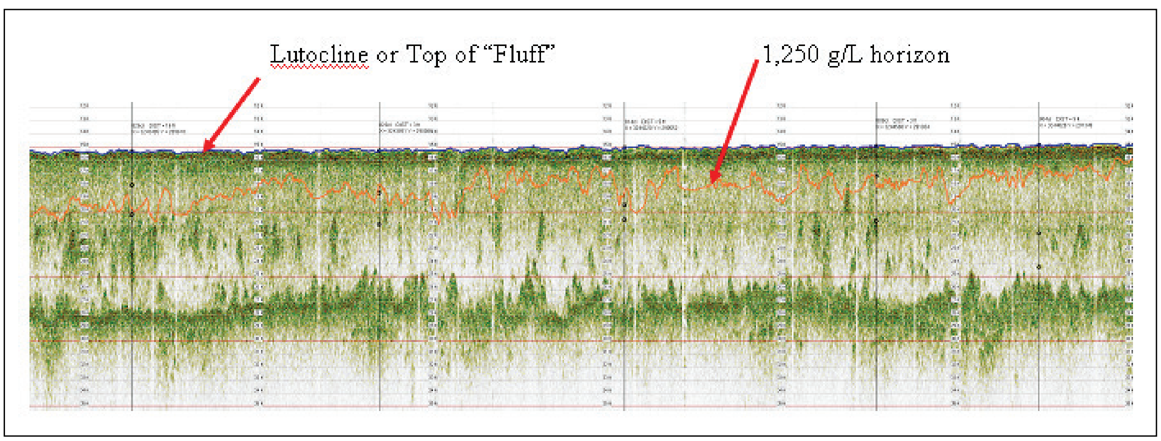


Figure 6. SILAS acoustically measured density horizon of 1.250 g/cm³ on 4 December 2011.



3 Data Analysis

The before- and after-drag Rheotune density and yield stress profiles were reduced and compared by various methods described in the following sections. Table 3 lists the stations at which there is Rheotune data, the dates and times at which plow-barge operations occurred at those stations, and the dates of the Rheotune surveys. SILAS density horizons were also analyzed and plotted to evaluate acoustically measured density values of the before- and after-drag conditions.

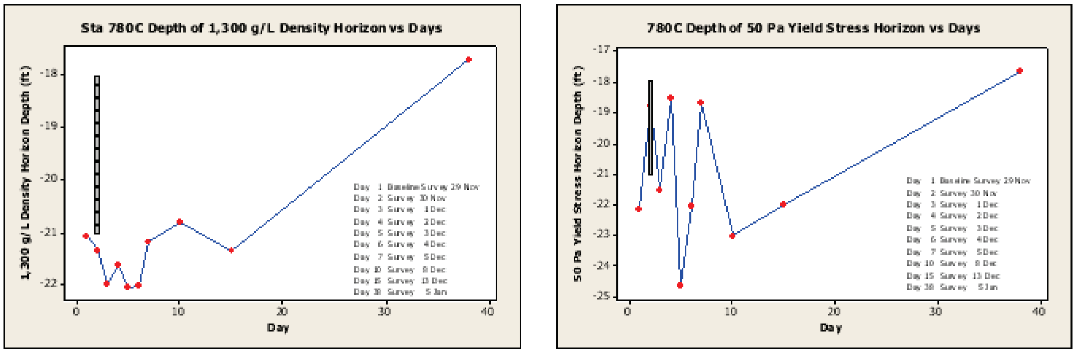
Table 3. Plow-barge operations and list of the dates for the nine surveys.

Stations	Plow-Barge Operations Dates	Surveys Before After
780, 784, 788, 792, 796, 800, 804, 808	11/30 1105 – 11/30 1810	11/29 12/1-12/5, 12/8, 12/13, 1/5
820, 826, 832	11/30 1820 – 11/30 2400	11/29, 11/30 12/1-12/5, 12/8, 12/13, 1/5
756, 762, 768	12/2 2200 – 12/3 0530	11/29-12/2 12/3-12/5, 12/8, 12/13, 1/5

Before the demonstration was conducted, a density value and yield stress value of 1.300 g/cm^3 and 50 Pa, respectively, were selected as the values where changes in their depths (elevations) could identify navigability changes induced from dragging the bedleveler. The depths where density and yield stresses values reached 1.300 g/cm^3 and 50 Pa were determined from the Rheotune centerline profiles before and after plow-barge operations and are given in Appendix A. These density and yield stress values were plotted vs. time (days) and are presented in Appendices B and C, respectively. Examples are presented in Figure 7.

The cross-hatched vertical rectangle on these plots illustrates the day that the bedleveler completed the respective pass (from Table 1). Its vertical dimension (3 ft) illustrates the bedleveler’s depth extent in relation to the depths at which 1.300 g/cm^3 and 50 Pa were measured.

Figure 7. Example plots of 1.300 g/cm³ density (a) and 50 Pa yield stress (b) depths plotted vs. time (days) with bedleveler completion day and depth extent indicated by rectangles.



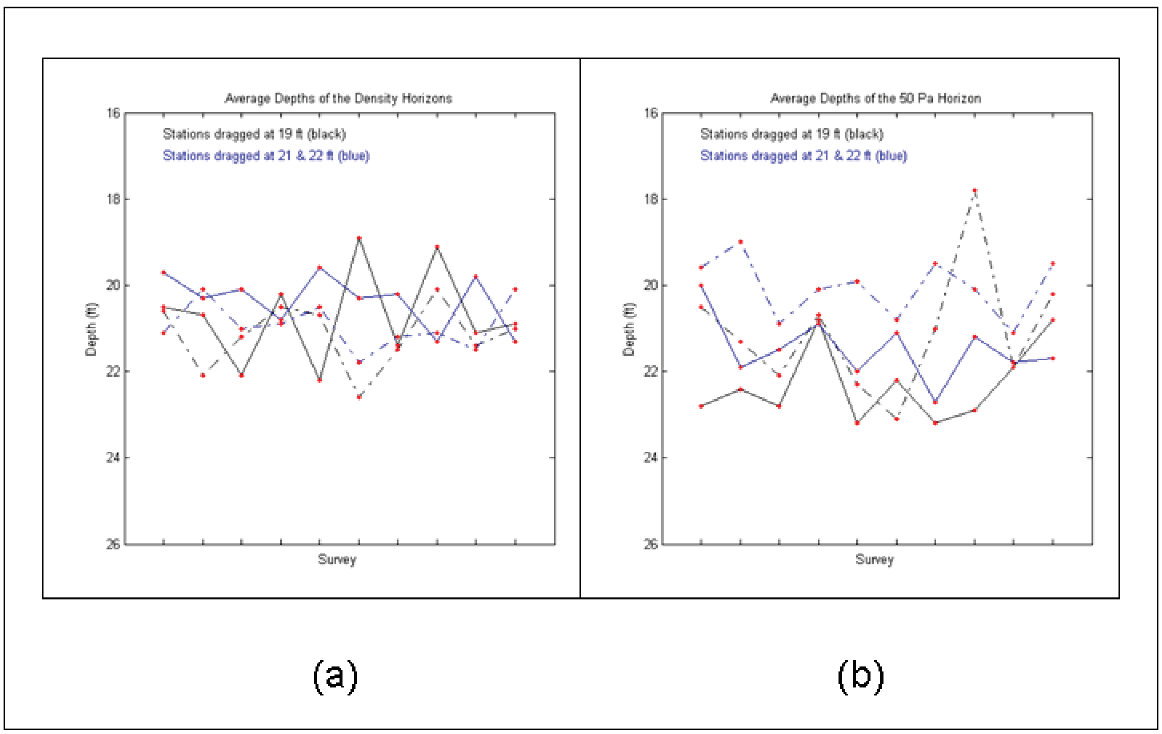
(a) (b)

The density and yield stress horizons shown in Figure 7 and presented in Appendices A through C were determined by selecting the first measurement in each profile (i.e., the shallowest depth) where the measured density value exceeded 1.300 g/cm³ or where the measured yield stress exceeded 50 Pa. Another way to analyze the data is to select the depth at which the density or yield stress exceeded a given value and remained greater than that value with increasing depth. This was done for the depths of the 1.250 g/cm³ density and 50 Pa yield-stress horizons. In a few cases (in 18 out of 280 profiles), single measurements were ignored if they appeared to be greatly different from the measurements above and below them. With these density and yield-stress horizon depths, and those present in Appendix A, averages were computed for each survey with the stations grouped in two ways. Since nearly all the horizon depths were greater than 19 ft, one grouping was the three stations (756, 762, and 768) where the drag depth was at 19 ft and most likely would only have an effect on depths 16 to 19 ft. The other grouping was the remaining 11 stations where the drag depth was either 21 or 22 ft and could have had an effect on most of the horizon depths. The results are plotted in Figure 8.

In Figure 8, the solid lines are for the 1.250 g/cm³ and 50 Pa horizons calculated by selecting the depths at which the measurements reached the horizon values and remained above them with increasing depth. The dashed lines are for the horizon depths selected as being for the first depth where the 1.300 g/cm³ and 50 Pa measurements were exceeded, without the requirement that they remain above these values with increasing depth. The horizontal axis in Figure 8 has uniformly spaced tick marks for each of the

10 surveys, unlike the plots in Figure 7 that have values for each survey versus a linear scale of days. However, Figure 8 still shows the change in the values with time and does not appear to show any overall long-term trends. To obviously demonstrate the feasibility of dragging the bedleveler to change mud properties, a deepening of the horizons after the baseline survey on 29 November 2011 (the first survey), and a possible recovery of the horizon depths on the last survey on 5 January 12 (32 days after the plow-barge operations were over), would need to be clearly shown in the figure. Presented in this manner, it appears that the tow-barge operations had very little or no effect on navigability. This conclusion led to a statistical analysis of the data to determine if there might be changes that were obscured by measurement errors or natural variability.

Figure 8. Example of average depths of the 1.250 and 1.300 g/cm³ density horizons (a) and the 50 Pa horizon depths (b), computed for all 10 surveys.



The Rheotune data are not error free. There are errors in measured values within individual vertical profiles as well as errors associated with repeatability. The errors in the measured values within individual vertical profiles are of two types. There are random measurement errors typical of any instrument, but there are also apparent data shifts associated with instrument stability. These shifts move entire profiles to unrealistic ranges of values not typical of the measurements made at the same locations

under similar conditions. The profile shifts aside, the errors associated with repeatability appear to be random errors. These errors result in a range of measured values from repeated profiles made at the same location under the same conditions.

Random errors are described by a Gaussian distribution. The true mean, or average, of a Gaussian distribution of measured values is the measurement that would be expected if there were no errors. The random errors within individual vertical profiles can be reduced by calculating vertical mean values over a distance that is significantly less than the distances over which important changes (i.e., changes that affect navigability) in mud density and yield stress occur.

Figure 9 shows vertical profiles of yield stress made at Station 762 on four consecutive days before plow-barge operations at this station. On the left side of the figure are profiles without any vertical averaging of the data. On the right are profiles of mean values calculated at the depth of each measurement. The means are the averages of the measurements at each depth and the two measurements made immediately before and after the measurements at each depth. This type of mean is referred to as running mean, and for these data it is made over a typical depth range of 0.2 ft above and below each depth where there are data. The profiles of averaged data have the same main features seen in the profiles plotted from data without vertical averaging, but the small scale variations are gone. The Rheotune data were first averaged in this manner at 0.4 ft averaging windows before any analyses were conducted.

The accuracy with which a calculated mean gives the expected value depends on the range of measurement errors quantified by the standard distribution and the number of measured values available for calculating the mean. The greater the number of measurements and the smaller the standard deviation, the closer the calculated mean value is to the expected value. To reduce errors (i.e., improve accuracy) related to repeatability, means were calculated using data from as many before-plow-barge operations surveys as possible and from four after-plow-barge operations surveys. A question arises when analyzing these mean values: Are they close enough to the expected values to show that the expected values are different, or is any difference between them inside the range of values possible in the differences between the calculated means and the expected

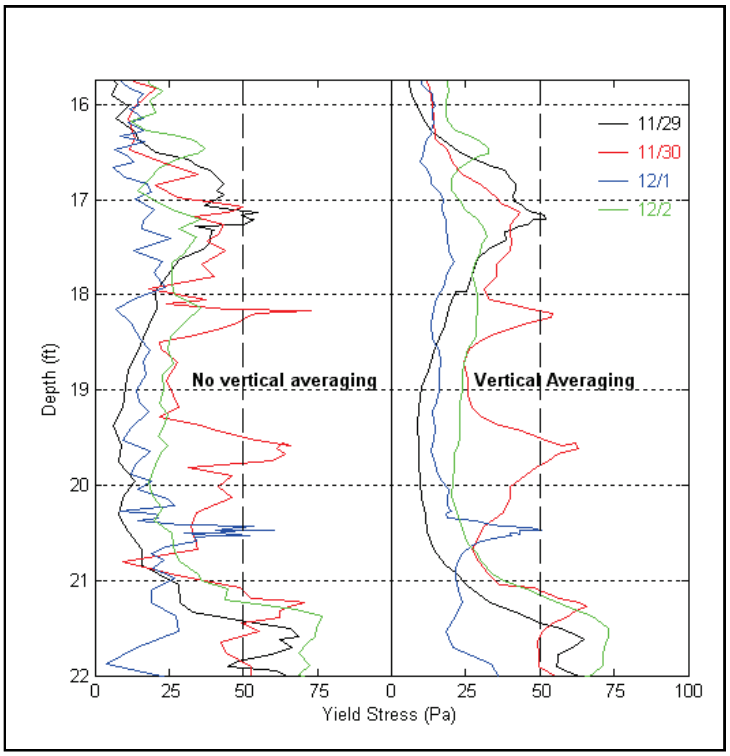
values? This question is tested using a z-test. The z-test statistic, **z,** gives the probability that the expected values are different and is given by

$$z = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{\sigma_1^2}{n_1} - \frac{\sigma_2^2}{n_2}}}$$

where:

$\overline{x}_1$ and $\overline{x}_2$ = the before and after mean yield stresses
σ_1 and σ_2 = the before and after standard deviations
n_1 and n_2 = the before-and-after number of measurements.

Figure 9. Vertical profiles of repeated Rheotune yield stress measurements made at the same location.



The observed shifted profiles cannot be considered to be random errors for these Rheotune data. However, the data values might be eliminated by a common statistical practice of eliminating measurements that are three standard deviations different than the mean. This was done in the first of the following two data analyses types. The first type of analysis treats all the errors as being random and eliminates measurements that are greater

than three standard deviations from the mean. To calculate the means and the standard deviations for the data elimination criteria, an assumption is made that any changes in density or yield stress that result from plow-barge operations are much smaller than three standard deviations from the means at each depth for all surveys (i.e., data from both before and after operations). This assumption is shown by the analyses to be valid.

The second type of data analyses introduces a subjective element. It eliminates entire profiles from the analysis if they appear to be shifted. There is no elimination of individual measurements based on their value relative to the mean. The second analysis was conducted to test the sensitivity of the conclusions made on the basis of the first type of analyses, compared to the treatment of all errors as being random.

The data elimination criteria based on the standard deviations were established by calculating the means and standard deviations of measurements for all surveys starting at 16 ft depth. Then the elimination criteria imposed from the analysis was applied if values were less than the water density (1.007 g/cm^3) or greater than the Rheotune penetration density at the 17, 18, 19, 20, 21, and 22 ft depths. For the density data, there was an additional initial criteria imposed that eliminated measurements from the analysis if they were less than the water density (1.007 g/cm^3) or greater than the Rheotune penetration density (1.350 g/cm^3). For the yield stress data, an initial criteria eliminated measurements greater than a physically unrealistic value of 250 Pa. The results for the density data are listed in Table 4. Table 5 lists the results for the yield-stress data.

Table 4. Density statistics determined for all stations.

Depth (MLG ft)	Mean Density (g/cm^3)	Standard Deviation (g/cm^3)	3 Standard Deviations + Mean* (g/cm^3)
16	1.192	0.036	1.300
17	1.218	0.032	1.313
18	1.227	0.036	1.335
19	1.237	0.038	1.350
20	1.250	0.044	1.350
21	1.266	0.049	1.350
22	1.285	0.050	1.350

*Maximum density the Rheotune can penetrate is taken to be 1.350 g/cm^3.

Table 5. Yield stress derived statistics for all stations.

Depth (MLG ft)	Mean Yield Stress (Pa)	Standard Deviation (Pa)	3 Standard Deviations + Mean (Pa)
16	7.4	8.1	31.6
17	19.0	15.6	65.7
18	26.7	19.8	86.2
19	33.6	28.7	119.8
20	37.9	32.0	134.0
21	45.9	27.7	129.0
22	61.4	32.6	159.1

4 Results

Density

Tables 6, 7, and 8 list the average before- and after-plow-barge operations densities at each depth. In these tables, the averages and standard deviations are computed using values for all stations affected by each operation, at each depth, from each survey. Rheotune survey data are available for varying numbers of days surrounding each plow-barge operation. For all three operations, there are 4 days of data available after each operation. For the third operation (Table 6), there are also 4 days of data available from before the operation. For the second operation (Table 7), there was only one survey conducted before the operation began. There was another survey conducted on 30 November 2011 shortly after that operation began when it was only 25% complete. Data from that survey are not used in the analyses. For the first operation (Table 8), there were two surveys done before the operation began. The dates of the surveys used in the analyses are listed in the tables.

Table 6. Mean densities before and after plow-barge operations at Stations 756, 762, and 768.

Depth (MLG ft)	11/29/11–12/2/11		12/3/11–12/8/11	
	Mean Density (g/cm^3)	Standard Deviation (g/cm^3)	Mean Density (g/cm^3)	Standard Deviation (g/cm^3)
16	1.178*	0.019	1.183	0.041
17	1.220	0.016	1.224	0.017
18	1.231	0.009	1.231	0.027
19	1.235	0.029	1.250	0.009
20	1.251	0.006	1.252	0.011
21	1.253	0.029	1.265	0.029
22	1.279[1]	0.022	1.278	0.023

*No data on 11/29 at Station 756.

[1]No data on 11/29 at Station 768.

Table 7. Mean densities before and after plow-barge operations at Stations 780, 784, 788, 792, 796, 800, 804, and 808.

Depth (MLG ft)	11/29/11		12/1/11–12/4/11	
	Mean Density (g/cm³)	Standard Deviation (g/cm³)	Mean Density (g/cm³)	Standard Deviation (g/cm³)
16	1.198	0.043	1.204	0.030
17	1.218	0.046	1.217	0.031
18	1.232	0.039	1.226	0.034
19	1.246	0.045	1.237	0.033
20	1.238	0.052	1.252	0.031
21	1.258	0.053	1.271	0.041
22	1.291	0.054	1.301*	0.044

*Measurement at Station 804 on 12/2 not included because it exceeded 1,350 g/cm³.

Table 8. Mean densities before and after plow-barge operations at Stations 820, 826, and 832.

Depth (MLG ft)	11/29/11–11/30/11		12/1/11–12/4/11	
	Mean Density (g/cm³)	Standard Deviation (g/cm³)	Mean Density (g/cm³)	Standard Deviation (g/cm³)
16	1.187	0.029	1.182	0.036
17	1.212	0.028	1.215	0.015
18	1.246	0.018	1.234	0.016
19	1.262	0.014	1.260	0.016
20	1.290	0.020	1.268	0.053
21	1.301	0.017	1.288	0.060
22	1.302*	0.040	1.295[1,2]	0.061

*No data on 11/29 at Station 826.

[1]Measurement at Station 820 on 12/2 not included because it exceeded 1.350 g/cm³. [2]Measurement at Station 826 on 12/4 not included because it exceeded 1.350 g/cm³.

Table 9 lists the probabilities based on the z-test value that the before- and after-plow-barge operations mean densities are not due to random error. Only three of the probabilities in Table 9 are greater than or equal to 75%, and there are an equal number (i.e., 10) of decreased and increased densities between the before-plow-barge operations and after-plow-barge operations. This indicates that the differences in the densities measured after the plow-barge operations and those measured before the plow-barge operations are likely due to chance. The conclusion from this is that the plow-barge had no demonstrated effect on mud density.

Table 9. Before and after plow-barge operations density z-test results.

Depth (MLG ft)	Z value		Probability (%)
	Stations 756, 762, and 768		
16	-0.38		30
17	-0.59		44
18	0		0
19	-1.71		91
20	-0.28		22
21	-1.01		69
22	0.11		9
	Stations 780, 784, 788, 792, 796, 800, 804, and 808		
16	-0.37		29
17	0.06		5
18	0.40		31
19	0.53		40
20	-0.73		53
21	-0.65		48
22	-0.48		37
	Stations 820, 826, and 832		
16	0.32		25
17	-0.25		19
18	1.38		83
19	0.27		21
20	1.27		80
21	0.70		52
22	0.27		21

Yield stress

The before- and after-plow-barge operations yield stress means and standard deviations are listed in Tables 10, 11, and 12, and the probabilities are listed in Table 13. The probabilities that the differences are not due to chance are greater than or equal to 75% in nine cases: at 18, 19, 20, and 22 ft at Stations 756, 762, and 768; at 16 and 22 ft at Stations 780 through 808; and at 18, 19, and 20 ft at Stations 820, 826, and 832. In each of these nine cases, the z value is positive, meaning that the yield stress was lower after the plow-barge operations.

Table 10. Mean yield stresses before and after plow-barge operations at Stations 756, 762, and 768.

Depth (MLG ft)	11/29/11–12/2/11		12/3/11–12/8/11	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
16	3.2*	2.0	5.7	8.5
17	20.6	10.4	21.2	17.4
18	30.3	20.2	21.2	11.8
19	28.9	22.5	20.9	9.1
20	26.0	24.5	16.4	5.8
21	30.4	21.6	28.9	18.3
22	40.1[1]	18.1	30.7	16.0

*No data on 11/29 at Station 756. [1]No data on 11/29 at Station 768.

Table 11. Mean yield stresses before and after plow-barge operations at Stations 780, 784, 788, 792, 796, 800, 804, and 808.

Depth (MLG ft)	11/29/11		12/1/11–12/4/11	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
16	12.4*	5.2	9.2[1,2]	5.6
17	25.0	14.6	20.5[3]	10.4
18	27.4[4]	10.3	27.9	12.3
19	33.9	26.8	37.6	19.7
20	46.0	32.9	41.1	18.7
21	53.2	26.1	44.2[5]	16.5
22	76.9	31.2	59.4[5]	15.2

*Measurement at Station 800 on 11/29 not included because it exceeded 3 standard deviations.
[1]Measurement at Station 784 on 12/4 not included because it exceeded 3 standard deviations.
[2]Measurement at Station 804 on 12/3 not included because it exceeded 3 standard deviations.
[3]Measurement at Station 804 on 12/4 not included because it exceeded 3 standard deviations.
[4]Measurement at Station 800 on 11/29 not included because it exceeded 3 standard deviations.
[5]Measurements at Station 800 on 12/2 not included because they exceeded 3 standard deviations.

Table 12. Mean yield stresses before and after plow-barge operations at Stations 820, 826, and 832.

Depth (MLG ft)	11/29/11–11/30/11		12/1/11–12/4/11	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
16	6.7	6.5	3.8	3.8
17	22.4	21.6	16.4	7.9
18	39.8	20.3	23.7	12.0
19	43.5	21.8	26.4	11.0
20	49.8	19.0	32.3	17.4
21	56.4	17.9	48.2	16.7
22	69.1*	18.4	63.5	11.4

*No data on 11/29 at Station 826.

Table 13. Before and after plow-barge operations yield stress z-test results.

Depth (ft)	z Value	Probability (%)
Stations 756, 762, and 768		
16	-0.99	68
17	-0.10	8
18	1.35	82
19	1.14	75
20	1.32	81
21	0.18	14
22	1.31	81
Stations 780, 784, 788, 792, 796, 800, 804, and 808		
16	1.44	85
17	0.82	59
18	-0.11	9
19	-0.37	29
20	0.41	32
21	0.93	65
22	1.54	88
Stations 820, 826, and 832		
16	1.01	69
17	0.66	49
18	1.79	93
19	1.81	93
20	1.89	94
21	0.94	65
22	0.63	47

For Stations 756, 762, and 768, the bottom of the plow was at 19 ft and primarily acted on the mud at depths of 16–19 ft. Table 11 shows that at depths 16 through 19 ft, the mean yield stresses were lower after the plow-barge operations than they were before the operations at 18 and 19 ft and higher at 16 and 17 ft; however, the net reduction in mean yield stress for these four depths was 14.0 Pa. For Stations 780, 784, 788, 792, 796, 800, 804, and 808, the plow was at 21 ft and acted on depths 18–21 ft. Table 11 shows that at depths 20 and 21 ft, the mean yield stresses were lower after the plow-barge operations and higher after the operations at 18 and 19 ft. There was a net reduction in mean yield stress for all four depths of 9.7 Pa. For Stations 820, 826, and 832, the plow was at 22 ft and acted on depths 19–22 ft. Table 12 shows that the mean yield stresses were lower after the plow-barge operations at all four depths, and the net reduction in mean yield stress was 48.4 Pa.

Tables 14 through 20 give mean yield stresses at each depth for each station and show that at Stations 756, 762, and 768, the mean yield stresses decreased between 16 and 19 ft in 7 out of 12 cases. Mean yield stress increased at Stations 756 and 768 at 16 ft, at Stations 762 and 768 at 17 ft, and at 19 ft at Station 756. For Stations 780 through 808, Tables 18 through 19 show that the mean yield stresses decreased between 18 and 21 ft in 13 of 31 cases, the 18 increases in mean yield stress being at Stations 780, 792, and 808 at 18 ft; at Stations 780, 784, 788, 804, and 808 at 19 ft; at Stations 780, 788, 796, 804, and 808 at 20 ft; and at Stations 780, 788, 792, 804, and 808 at 21 ft. For Stations 820, 826, and 832, Tables 17 through 20 show mean yield stress decreases between 19 and 22 ft in 10 of 12 cases. At station 832 at 21 ft, there was no change, and mean yield stress increased at Station 826 at 22 ft.

Since there are mean yield stress reduction probabilities over 75% at nine depths and the only depths that had an increase had probabilities of 68%, 8%, 9%, and 29% (Table 13), it cannot be ruled out that the plow-barge operations did reduce yield stress in some places. However, the results are very inconsistent. For example, at Stations 820, 826, and 832 (Tables 13), where the plow-barge was towed at 22 ft, there were reductions in mean yield stress at 19 ft with a 93% probability and at 20 ft with a 94% probability; however, at 18 ft, 1 ft above the plow, there was a reduction in mean yield stress, which also had a 93% probability. At 22 ft, the depth of the bottom of the plow and at 21 ft the probabilities of the decreases in yield stress were only 47% and 65%. For stations 756, 762, and 768 where

the plow was towed at 19 ft, the data results show increased yield stress at 16 ft and 17 ft. The increase at 16 ft had the highest probability of the four observed increases (i.e., 68%).

Notes for Tables 14–21:

*No data on 11/29.
[1]Measurement on 11/29 not included because it exceeded 3 standard deviations.
[2]Measurement on 12/4 not included because it exceeded 3 standard deviations.
[3]Measurements on 12/2 not included because they exceeded 3 standard deviations.
[4]Measurements on 12/3 not included because they exceeded 3 standard deviations.

Table 14. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 16 ft.

Station	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	4.1*	1.6	8.5	13.5
762	2.4	1.2	1.9	1.5
768	3.4	2.9	6.6	7.2
780	10.4	NA	10.7	6.6
784	18.2	NA	7.8[2]	5.7
788	9.6	NA	7.7	5.4
792	5.6	NA	7.9	4.2
796	20.5	NA	10.4	5.5
800	38.9	NA	7.8	4.5
804	12.0	NA	13.4[4]	12.4
808	10.6	NA	9.2	1.7
820	6.6	6.5	6.9	5.3
826	6.7	7.8	3.5	1.7
832	2.9	3.0	1.1	0.4

Table 15. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 17 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	23.7	11.7	16.0	10.9
762	14.6	2.7	18.2	15.2
768	23.6	13.3	29.3	24.9
780	12.4	NA	21.6	8.0
784	26.0	NA	23.1	8.3
788	19.5	NA	20.2	9.1
792	16.0	NA	15.3	6.0
796	16.0	NA	26.7	20.5
800	58.5	NA	20.1	6.6
804	29.2	NA	19.7[4]	11.9
808	22.1	NA	16.7	12.2
820	10.4	9.4	15.5	4.0
826	17.1	4.3	21.1	7.6
832	13.8	9.8	12.6	10.1

Table 16. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 18 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	21.7	7.7	20.5	3.2
762	32.5	15.7	21.1	9.4
768	36.6	32.2	22.0	20.4
780	22.6	NA	30.5	8.1
784	30.4	NA	29.4	10.2
788	30.6	NA	25.2	9.4
792	15.1	NA	23.5	10.1
796	33.1	NA	30.0	11.6
800	NA[1]	NA	23.5	6.2
804	44.2	NA	37.5	22.7
808	15.8	NA	23.9	16.8
820	36.2	40.3	20.2	8.7
826	38.5	0.4	36.4	10.0
832	36.8	20.4	14.5	2.6

Table 17. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 19 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	19.6	3.1	24.7	12.3
762	28.0	13.4	19.0	5.6
768	39.2	37.5	19.0	9.5
780	16.9	NA	35.5	14.4
784	22.6	NA	41.9	19.8
788	19.7	NA	42.0	27.2
792	27.8	NA	27.5	11.1
796	49.6	NA	39.8	26.4
800	94.4	NA	34.6	9.2
804	26.0	NA	49.5	34.8
808	14.0	NA	29.6	8.1
820	48.0	40.0	22.1	6.9
826	40.2	20.0	28.9	11.3
832	42.2	17.8	28.3	15.1

Table 18. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 20 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	22.5	5.3	16.0	3.8
762	18.8	7.3	15.2	2.7
768	36.5	43.5	18.0	9.8
780	17.2	NA	46.8	26.2
784	87.2	NA	57.2	21.5
788	14.9	NA	38.1	18.2
792	46.0	NA	23.7	10.8
796	43.5	NA	46.5	24.4
800	103.4	NA	33.7	6.7
804	19.1	NA	42.2	19.4
808	36.6	NA	40.5	9.1
820	45.1	36.6	25.2	13.2
826	57.1	2.6	32.2	4.1
832	47.3	17.3	39.5	27.9

Table 19. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 21 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	29.8	6.0	18.7	7.8
762	22.2	12.8	28.4	21.0
768	39.2	36.2	39.4	20.9
780	40.4	NA	49.5	23.6
784	83.9	NA	48.7	24.3
788	17.2	NA	35.8	9.3
792	37.6	NA	41.3	7.9
796	52.2	NA	43.9	20.0
800	98.5	NA	30.9[3]	5.8
804	44.4	NA	46.0	18.3
808	51.4	NA	54.2	13.5
820	51.4	34.7	46.8	10.6
826	62.7	13.2	42.6	7.1
832	55.1	9.8	55.1	27.4

Table 20. Mean yield stresses before and after plow-barge operations for the stations in Table 3 at a depth of 22 ft.

Depth (MLG ft)	Before Operations		After Operations	
	Mean Yield Stress (Pa)	Standard Deviation (Pa)	Mean Yield Stress (Pa)	Standard Deviation (Pa)
756	34.6	12.9	19.5	5.5
762	29.9	9.3	32.3	8.4
768	61.0*	18.4	40.5	23.4
780	42.7	NA	66.1	10.1
784	88.3	NA	60.7	24.7
788	55.3	NA	58.5	22.9
792	57.5	NA	55.7	4.5
796	88.9	NA	53.8	24.6
800	143.4	NA	56.1[3]	6.4
804	66.5	NA	58.1	14.1
808	73.0	NA	65.4	7.2
820	75.5	18.2	58.6	9.9
826	44.8*	NA	62.5	10.3
832	74.9	17.0	69.3	14.0

The second type of yield-stress analysis in which entire profiles were excluded if they appeared to be shifted is illustrated in Figures 10 through 21. Figures 10, 11, and 12 show yield-stress profiles, grouped by stations and therefore grouped by plow-barge operations, from before the operations. They were plotted and analyzed using the 5-point running vertical averages from each before-operations survey, at each station. The running averages calculated at each depth where data existed were placed in 0.25 ft depth bins according to their depth, and the measurements in each bin were averaged to produce single average values at 0.25 ft intervals, starting at 15.75 ft and going down to 22 ft. This was done to make comparisons between profiles at consistent depth intervals. In the figures, the profiles that appear to be shifted are marked with asterisks. The after-operations profiles were averaged in the same way as the before-operations data and are shown in Figures 13, 14, and 15. The shifted profiles are also marked with asterisks in these figures.

Figure 10. Before plow-barge operations Rheotune yield-stress profiles at Stations 756, 762, and 768.

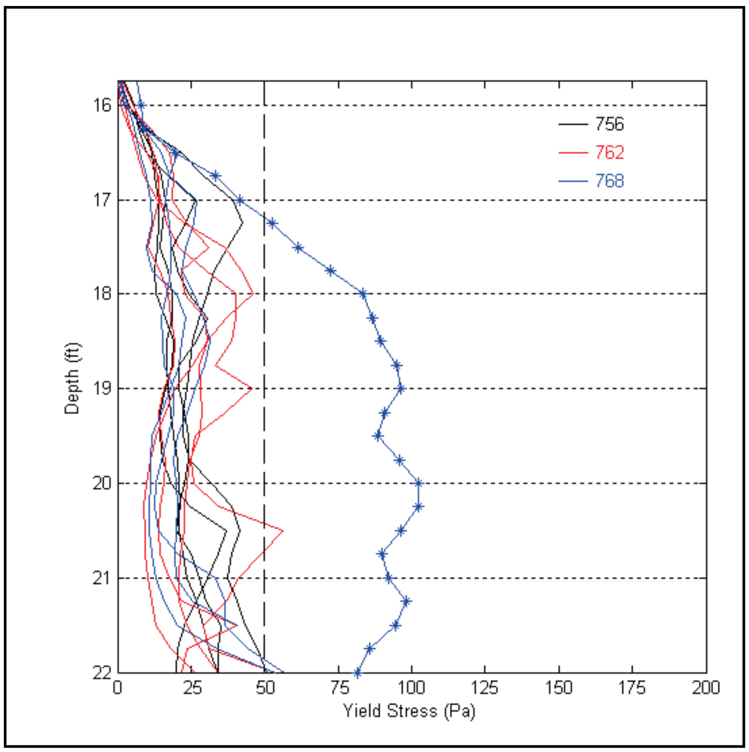


Figure 11. Before plow-barge operations Rheotune yield-stress profiles at Stations 780–808.

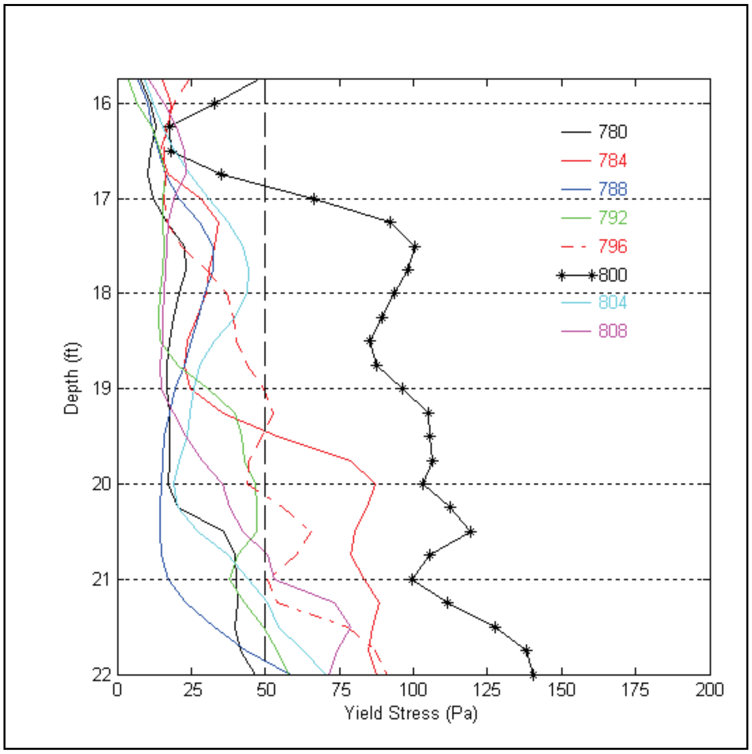


Figure 12. Before plow-barge operations Rheotune yield-stress profiles at Stations 820, 826, and 832.

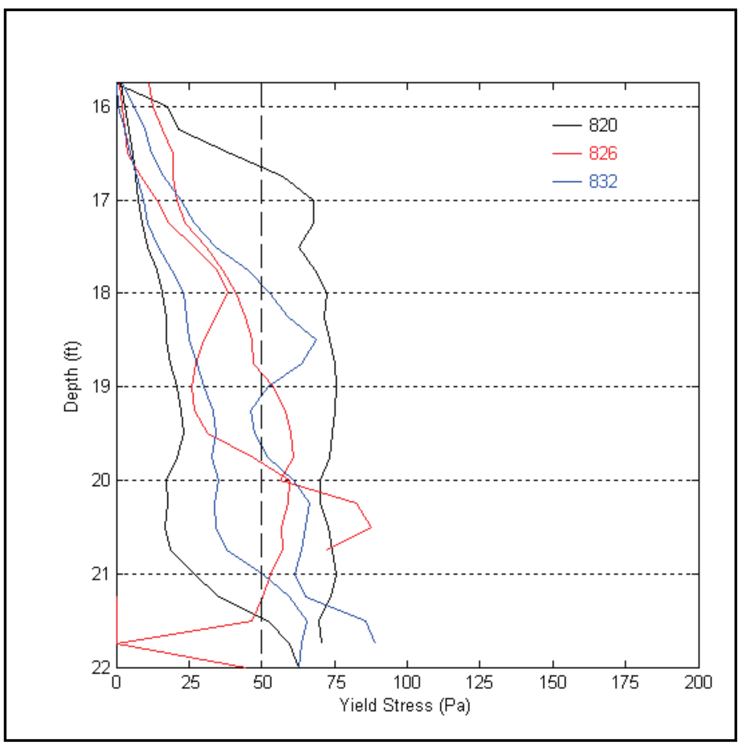


Figure 13. After plow-barge operations Rheotune yield-stress profiles at Stations 756, 762, and 768.

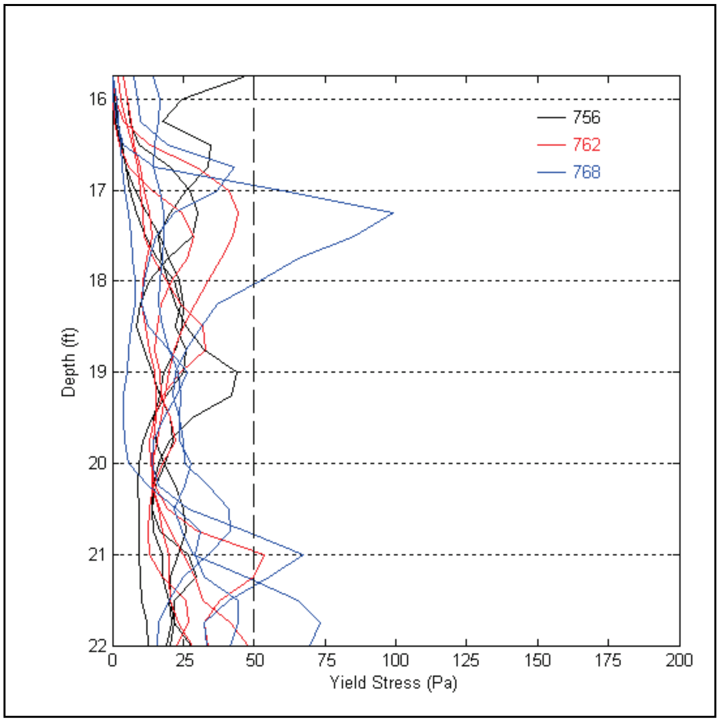


Figure 14. After plow-barge operations Rheotune yield-stress profiles at Stations 780–820.

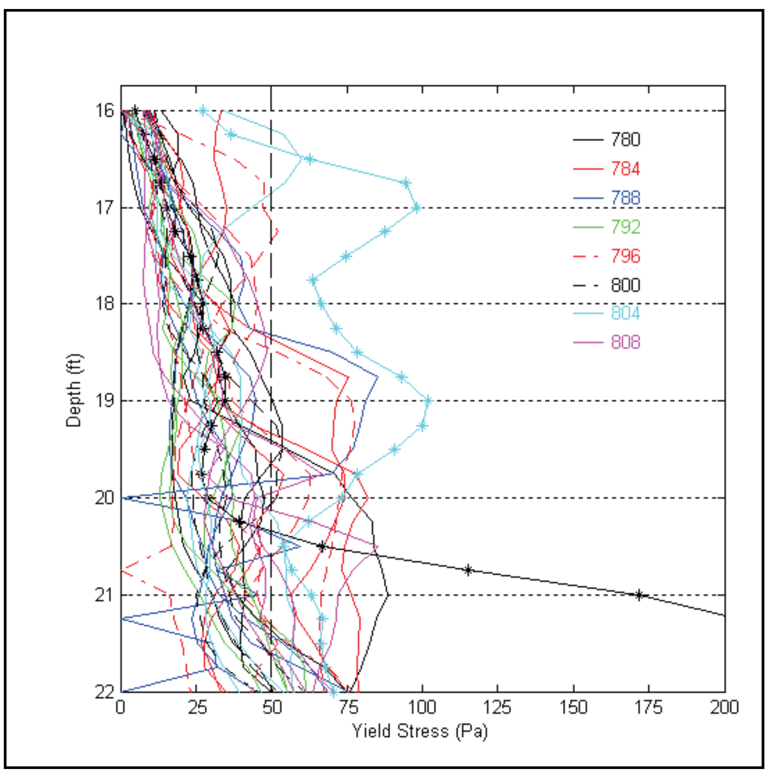


Figure 15. After plow-barge operations Rheotune yield-stress profiles at Stations 820, 826, and 832.

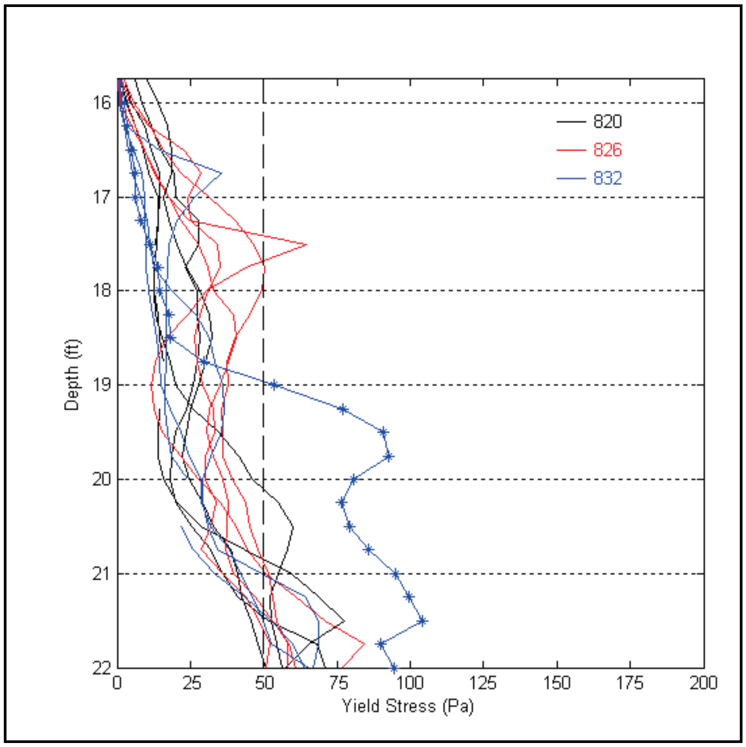


Figure 16. Before (-) and after (-*) plow-barge operations average Rheotune yield-stress profiles at Stations 756, 762, and 768.

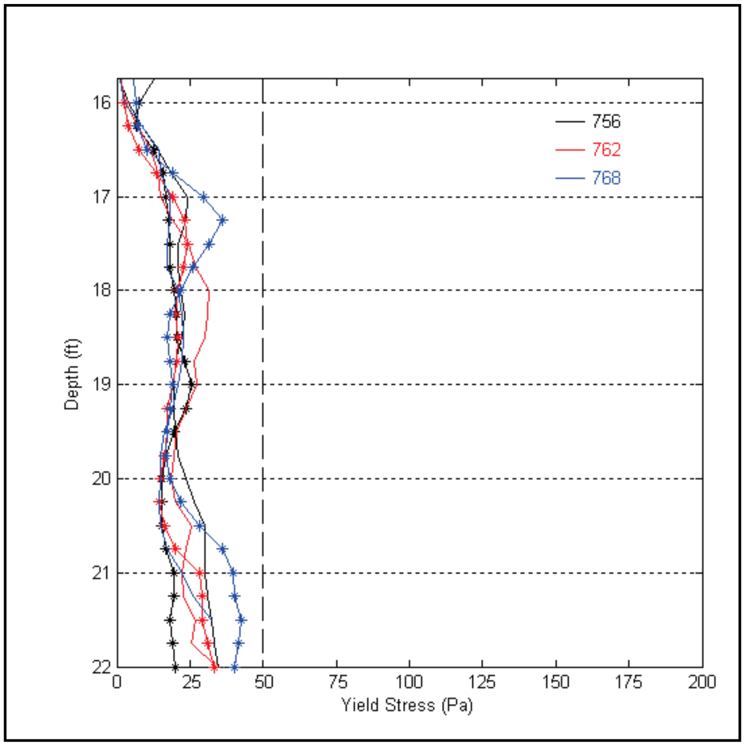


Figure 17. Before (-) and after (-*) plow-barge operations average Rheotune yield-stress profiles at Stations 780–808.

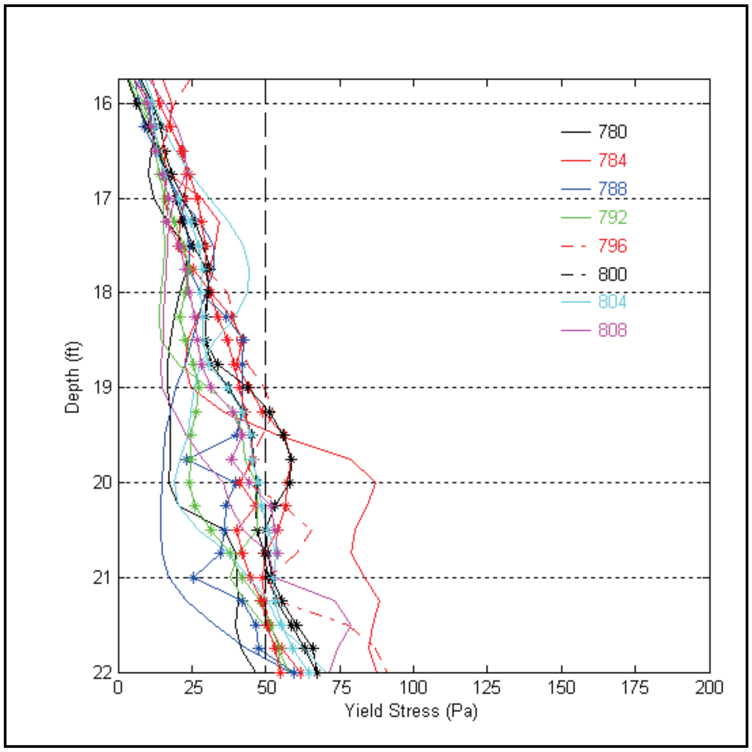


Figure 18. Before (-) and after (-*) plow-barge operations average Rheotune yield-stress profiles at Stations 820, 826, and 832.

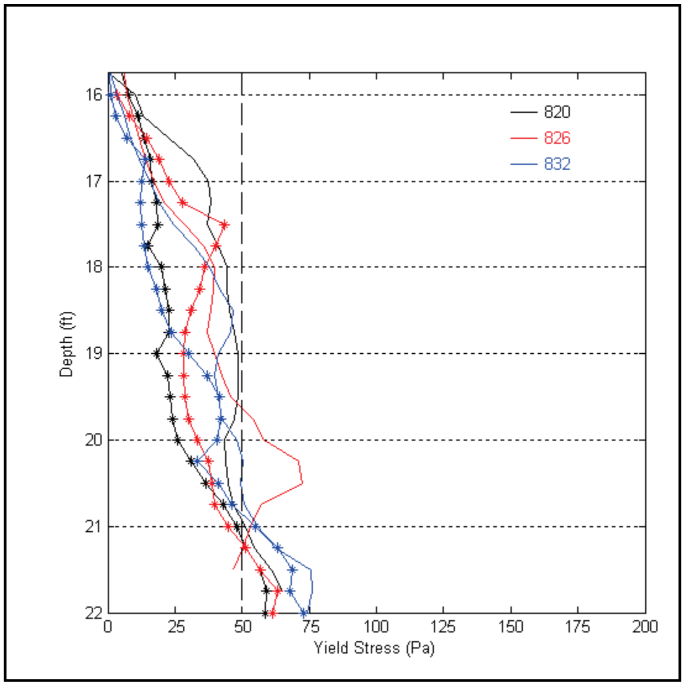


Figure 19. Difference between the average before and after average plow-barge operations profiles at Stations 756, 762, and 768.

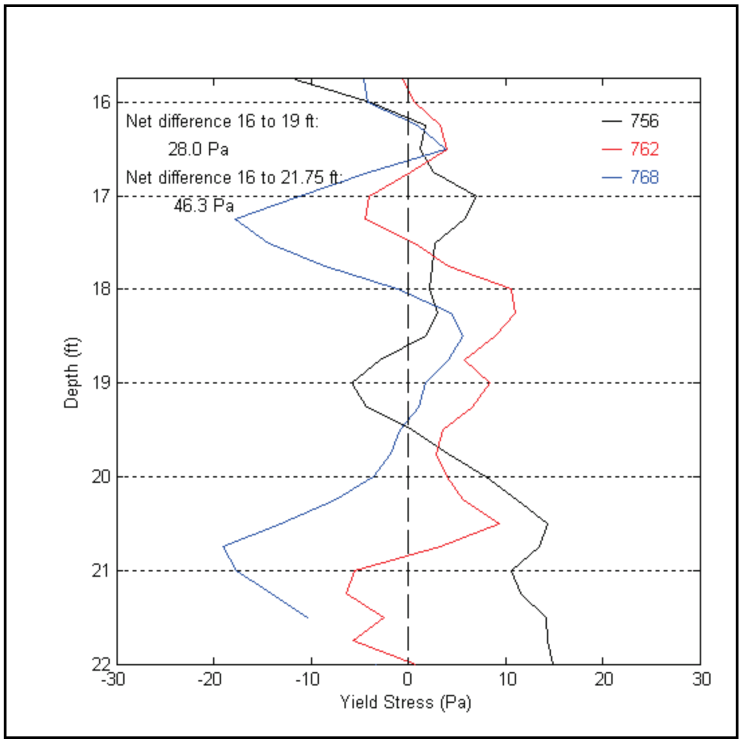


Figure 20. Difference between the average before and after average plow-barge operations profiles at Stations 780–808.

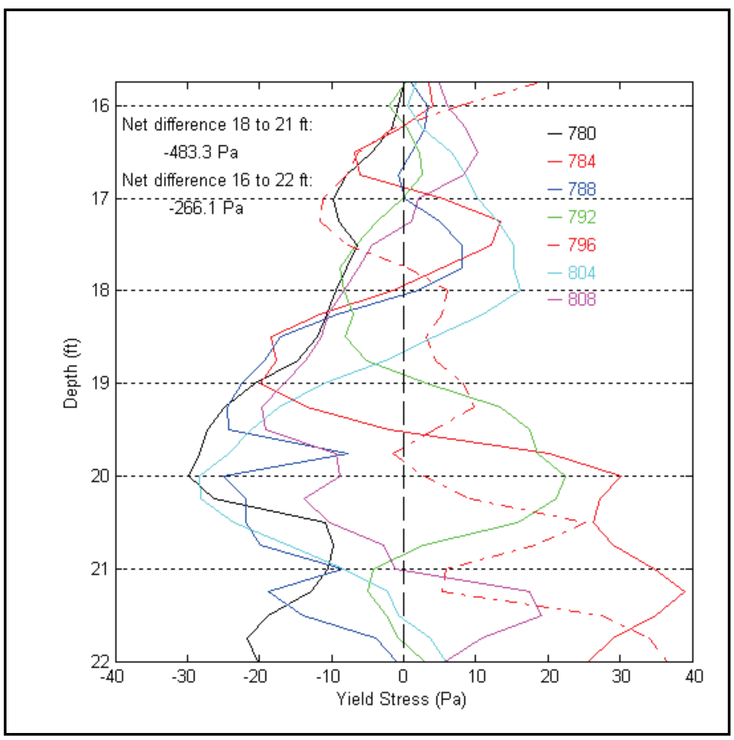
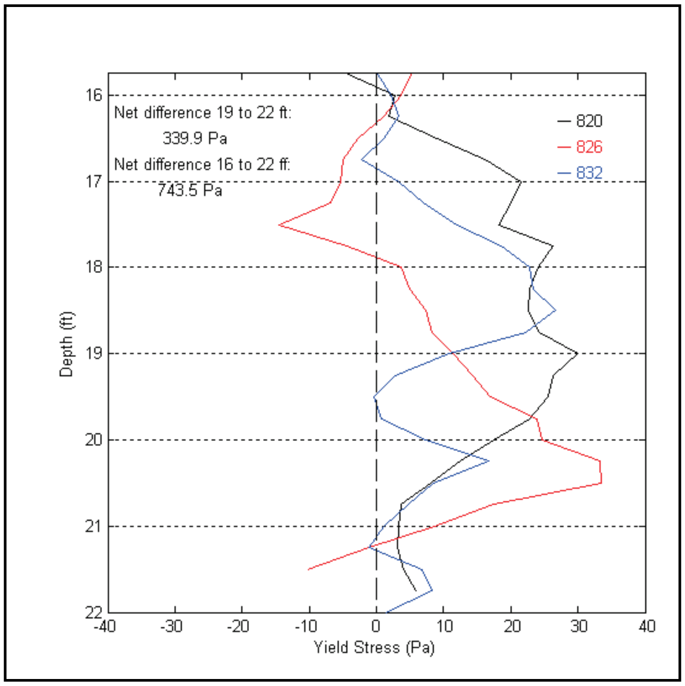


Figure 21. Difference between the average before and after average plow-barge operations profiles at Stations 820, 826, and 832.



The other method to analyze the profiles was to average the profiles that were not excluded at each station, for the before- and after-operations surveys. For example, at Station 762 there were four surveys conducted before the plow barge operations on 29 November 2011 through 2 December 2011. None were excluded, so at each 0.25 ft interval an average was calculated from the four values at the same 0.25-interval depths, from each of the four surveys.

The results are shown in Figures 16, 17, and 18. In these figures, the after-operations average profiles are marked with asterisks. The differences between the before- and after-operations profiles are shown in Figures 19, 20, and 21. Any changes in the yield stresses resulting from the plow-barge operations would be evident. In these figures, a positive difference means that the yield stress was lower after the plow-barge operation than it was before the operation.

Analyzing the data by this method produces results that differ somewhat from the first method. For example, Table 17 shows a decrease in mean yield stress at 18 ft at Station 768, from 36.6 Pa before plow-barge operations to 22.0 Pa after plow-barge operations. However, Figure 19 shows a small increase in mean yield stress for Station 768 at 18 ft. This is

because in the first method a yield stress of 83.6 Pa was measured on 2 December 2011. This before-operations measurement was not excluded in the first method of analysis because it was less than three times the standard deviation (i.e., 86.2 Pa, Table 10). In this analysis, the profile that produced the 83.6 Pa value was excluded because it appeared to be shifted (Figure 10).

Figure 19 shows that the net difference in yield stress from before to after plow-barge operations at Stations 756, 762, and 768 was a decrease of 28.0 Pa from 16 to 19 ft where the plow was towed and 46.3 Pa over the whole profile from 16 to 22 ft. Figure 20 shows that at Stations 780 through 808, there was a net increase in yield stress from 18 to 21 ft of 483.3 Pa where the plow was towed and a net increase in yield stress of 266.1 Pa for the entire profile. In Figure 21, the plow was towed between 19 and 22 ft at Stations 820, 826, and 832, and there was a net decrease in yield stress in this region of 339.9 Pa. Over the entire profile there was a net decrease of 743.5 Pa at these stations.

Since there were net decreases in yield stress over the range of depths that the plow was towed for two of three plow-barge operations (Stations 756–768, and 820–832), it cannot be entirely ruled out that the operations did, and are capable of, reducing the overall yield stress. However, the relatively large increases in yield stress observed at Stations 780 through 808 over the range of depths that the plow was towed stands out as an obvious inconsistency.

SILAS data

SILAS data collected from the *TECHE*'s echosounder system were analyzed to acoustically measure various density horizons. Figures 22, 23, and 24 show the SILAS survey transect along the channel centerline. In Figure 22, the black line denotes the 1.300 g/cm^3 density horizon surveyed 11 November 2011, and the red trace represents the 1.300 g/cm^3 horizon surveyed 4 December 2011. The plot graphically illustrates the dispersion, or variability, of the pre- and post-drag density values quantified in the previous Rheotune data analysis sections. Visual comparison of these two lines may provide insight to the fluid mud's reconsolidation characteristics on a temporal scale. For Test 3 (Stations 756–768, bottom, right-hand portion of transect in the figure), the post-drag (red) trace in Figure 22 is consistently deeper than the pre-drag (black) trace in comparison to the rest of the survey transect. This may be due to the fact that Test Area 3 was

dragged (finished 0530 hr on 3 December 2011) just the day before it was surveyed on 4 December 2011. In comparison, the pre- and post-drag (black and red) traces in Test Section 1 (Stations 780–808), dragged 30 November 2011 (finished at 1810 hrs), are closer together and overlap more often, potentially indicating that the fluid mud had consolidated more over the 4-day interval than it did in Test Area 3 in 1 day. However, Test Section 3 was dragged with the bottom of the bedleveler at 19 ft while the other two test areas (shown in the upper portion of the transect in the figure) were dragged with the bedleveler at 21 and 22 ft. This may be a factor that could affect this interpretation.

Figure 23 shows the pre- (brown trace) and post-drag (orange trace) 1.250 g/cm^3 density horizons along the survey transect. Within the context of the entire transect, these traces also illustrate the density value variability observed in Figure 22 and to a lesser degree, the fluid mud spatial re-consolidation interpretation between Test Areas 1 and Test Sections 2 and 3 that were previously discussed. Figure 24 shows the spatial relationship between the 1.250 g/cm^3 and 1.300 g/cm^3 density horizons as surveyed on 29 November 2011 and 4 December 2011. Over most of the survey transect, they track each other in their vertical excursions and maintain an approximate 2 ft vertical separation.

Figure 22. SILAS acoustically measured horizons along centerline of ABC. Black trace 1.300 g/cm^3 horizon surveyed 11 November 2011. Red trace 1.300 g/ figure cm^3 horizon surveyed 4 December 2011.

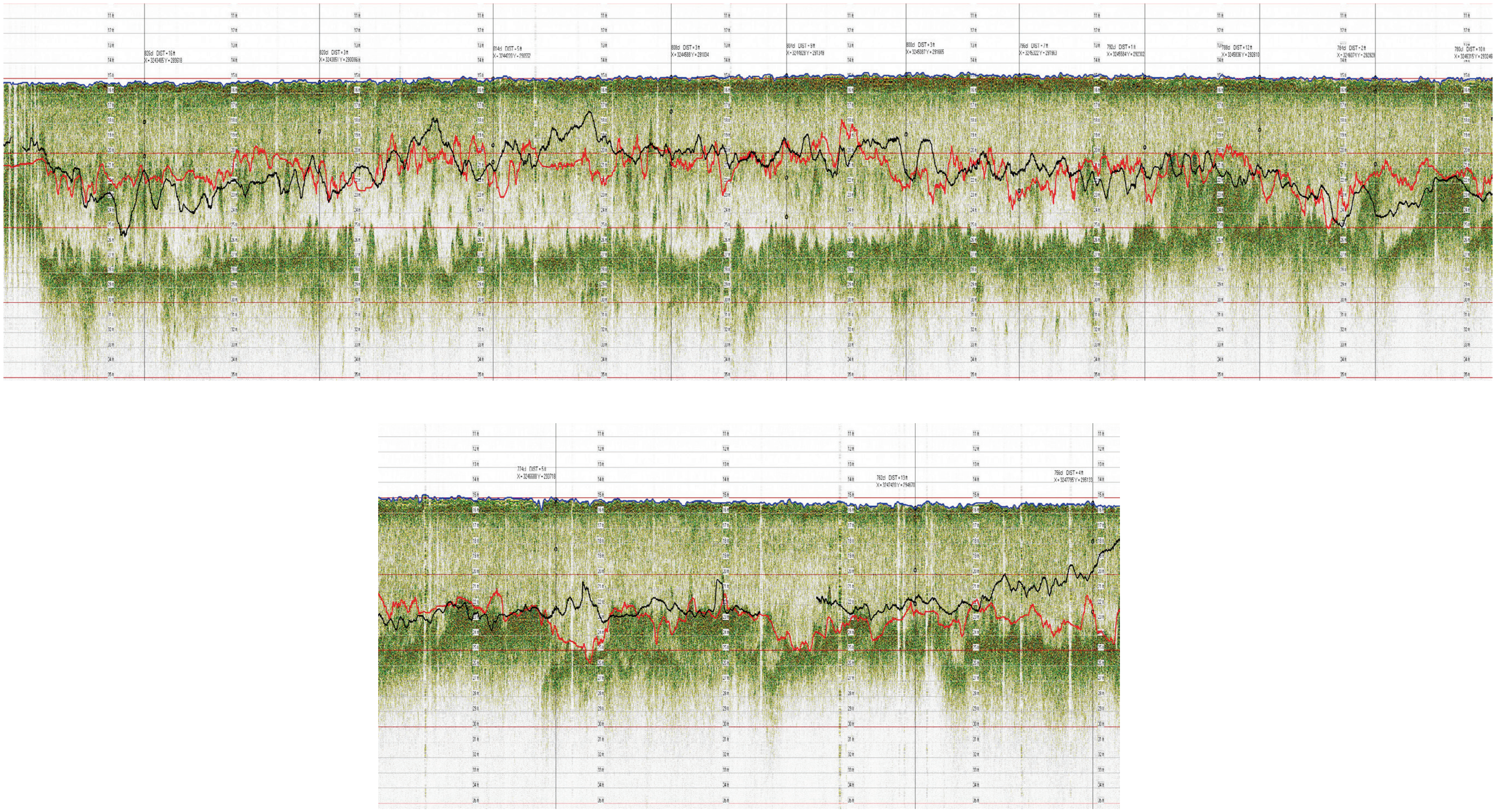


Figure 23. SILAS acoustically measured horizons along centerline of ABC. Brown trace 1.250 g/cm³ horizon surveyed 29 November 2011. Orange trace 1.250 g/cm³ horizon surveyed 4 December 2011.

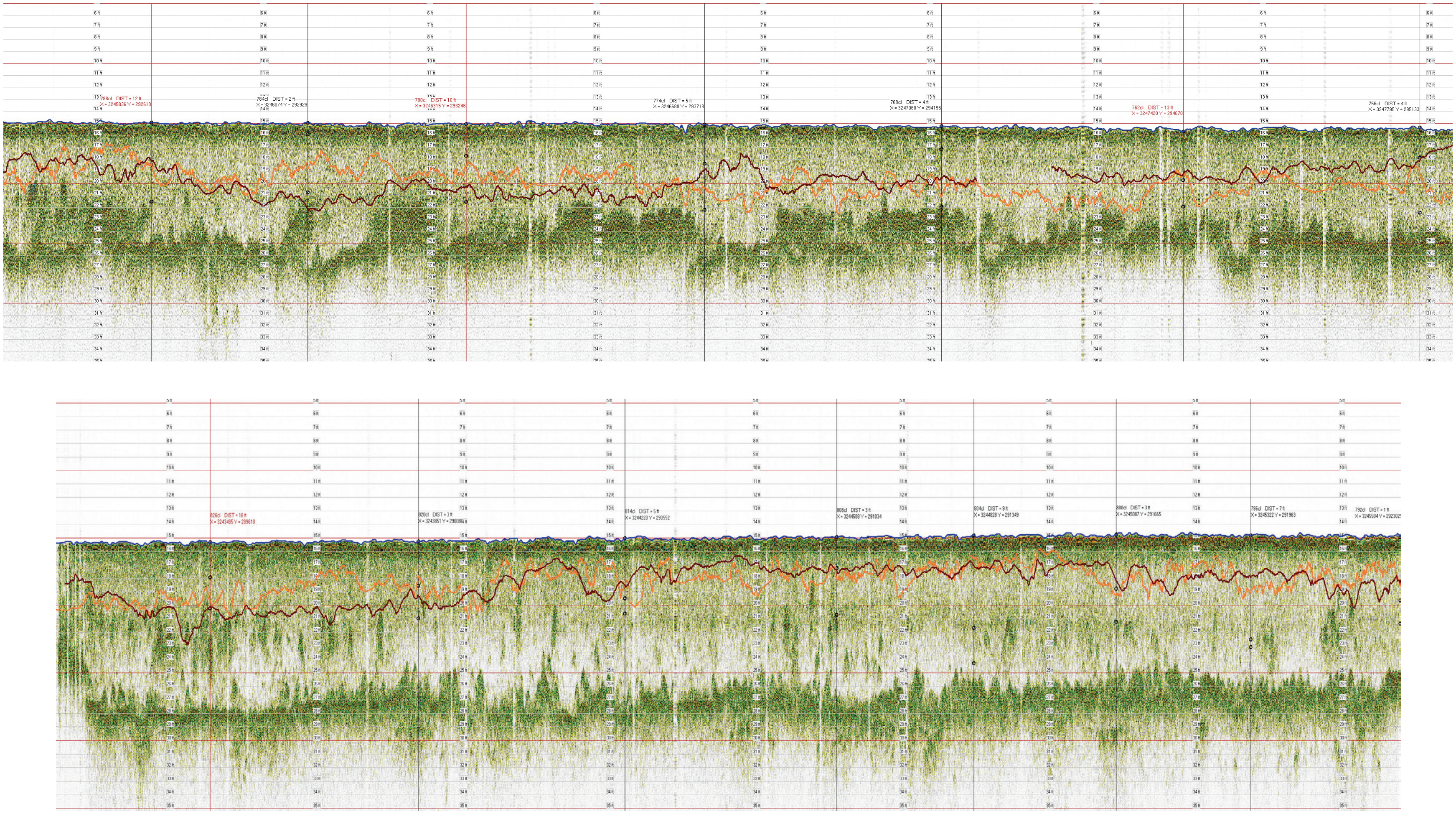
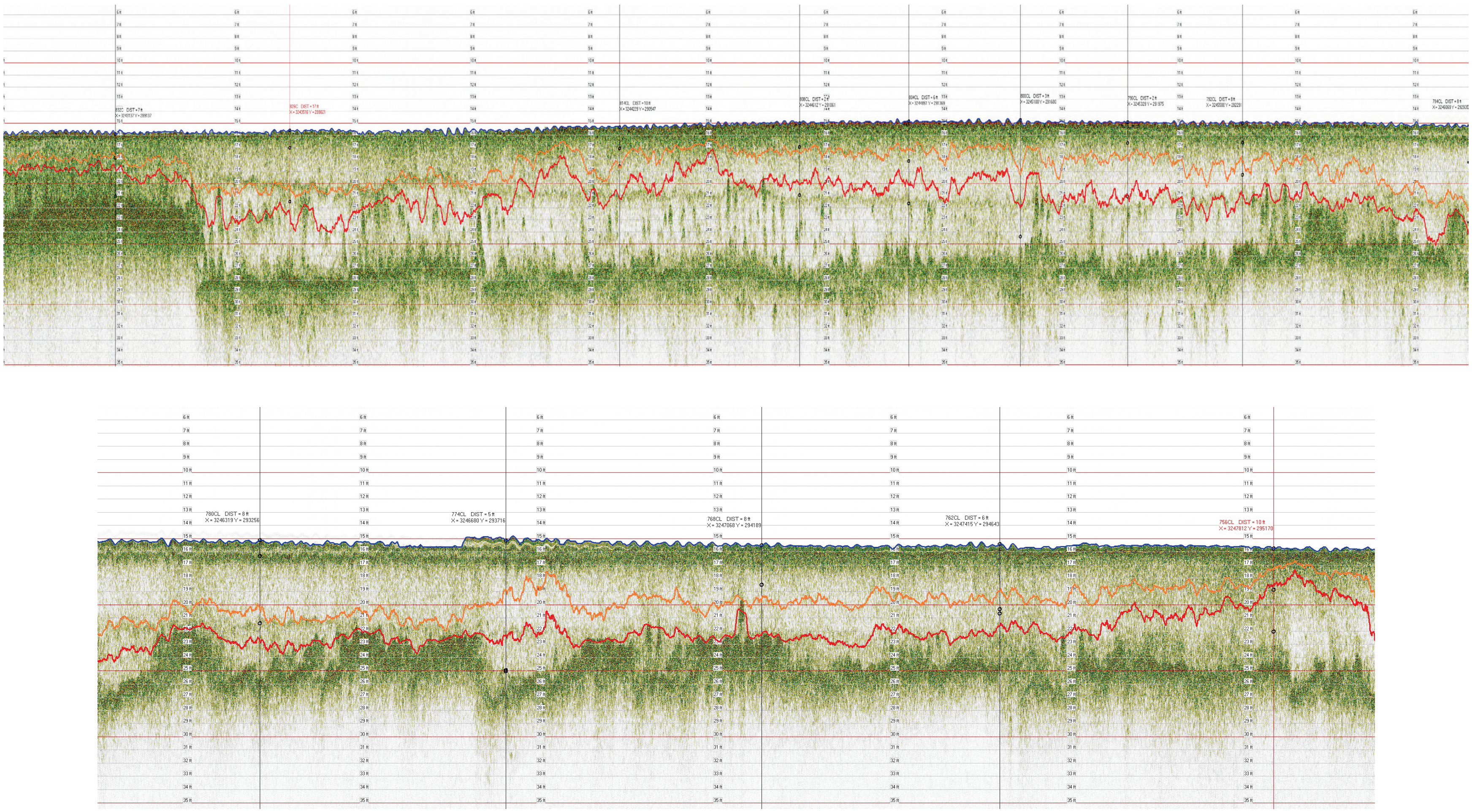


Figure 24. SILAS acoustically measured horizons down centerline of ABC. Orange trace is 1.250 g/cm³ horizon, and red trace is 1.300 g/cm³ horizon surveyed 29 November 2011.



5 Discussion

This study was undertaken with the goal of proving a technology that could be applied to the ABC to easily and economically lengthen the time between conventional navigation dredging of the channel. It was based on the known potential for in situ conditioning of bottom fluid-mud sediments to break down inter-floc bonds and lower densities and yield strengths, thereby facilitating ship passage. The proposed method of conditioning was dragging a large steel beam (a bedleveler) through the fluid mud using a push-barge and tug. The towing operations were conducted without significant problems. Ship traffic in the channel was essentially nonexistent during the study, and no significant wave or currents were observed.

To evaluate the effect of the bedleveler operations on the channel fluid mud, a Stema Systems survey system consisting of a Rheotune and SILAS was used to measure fluid-mud densities and yield stresses before and after the plow-barge operations. CHL has conducted laboratory and field tests of the ability of the Rheotune to measure sediment densities and has concluded that with calibrations using sediments from the area in which the measurements are conducted (as was done for this study), the instrument can be relied on to produce density measurements that are sufficiently accurate to determine changes in sediment densities that would be significant in terms of channel navigability. The system's ability to measure yield-stress changes has not been verified by CHL, but it has been determined to be affective in other non-Corps operations via unpublished commercial surveys.

The data produced by the Stema System were analyzed by two methods that were capable of revealing significant effects from the plow-barge operations on the sediment properties. In regards to density, the plow-barge operations seem to have had no effect or an extremely limited effect over a short duration. Both types of Rheotune analysis lead to the same basic conclusions in regards to yield stresses. It cannot be ruled out that the plow-barge operations had an effect on yield stresses, but the measured decreases were so inconsistent that naturally occurring changes or some other factors had a larger effect. A check of ship traffic in the area

during the time covered by the surveys indicates that was not a factor in possible changes in bottom characteristics. What other factors might have contributed to the variability of the density and yield stress measurements (including the possibility of instrument noise) are unknown. Neither analysis shows a region where the bedleveler was towed that there were decreases in yield stress at all stations, for all 3 ft of bedleveler depth. The results of the analysis show that the plow-barge operations did not effectively decrease yield stress in the fluid mud.

6 Conclusions

Plow-barge operations, consisting of dragging a large steel beam through fluid mud in the ABC, were conducted to demonstrate the potential for using the method to condition the bottom sediments and improve the navigability of the Channel. Fluid mud densities and yield stresses were measured before and after the plow-barge operations, using a Stema Survey system. The data were analyzed by two methods to determine the potential variance in errors, neither of which demonstrated a change in these sediment properties that could be navigationally significant. The results of the study show that the plow-barge operations did not effectively decrease yield stresses and densities of the fluid mud. Therefore, the use of this method to lengthen the time between conventional dredging of the channel was determined to be ineffective.

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Wurpts, R. W., and N. Greiser. 2007. Monitoring and dredging technology in muddy layers. In *Proceedings of World Dredging Congress (WODCON) XVIII, Lake Buena Vista Florida*. https://westerndredging.org/index.php/woda-conference-presentations/category/63-session-6a-survey-and-positioning-equipment

Appendix A: 1.300 g/cm³ and 50 Pa Depths

The depths in Table A-1 are (for Density, Den) the shallowest depth (ft) where a Density of 1.300 g/cm³ was measured (unless otherwise indicated) and (for Yield Stress, YS) the shallowest depth where a Yield Stress of 50 Pa was measured.

Table A-1. Shallowest depth (ft) where Density (Den) of 1.300 g/cm³ and Yield Stress (YS) of 50 Pa were measured (unless otherwise indicated).

	11/29/2011		11/30/2011		12/1/2011		12/2/2011		12/3/2011	
Station	Den	YS	Den	YS	Den	YS	Den	YS	Den	YS
756	22.4	21.8	23.1	23.0	23.0	22.2	22.5	22.7	22.1	23.6
762	20.9	17.9	22.1	19.0	22.3	21.4	22.0	22.3	22.3	22.8
768	18.5*	21.8	21.2*	21.9	18.2*	21.9	17.0*	17.1	17.6*	21.4
780	21.1	22.1	21.3	18.8	22.0	21.5	21.6	18.5	22.1	24.6
784	22.9	19.5	21.1	22.6	21.5	19.1	25.0	19.1	21.7	23.1
788	21.6	21.8	21.9	16.6	22.2	21.9	21.3	21.4	21.6	18.2
792	18.9	20.5	17.3	17.6	20.5	21.3	21.1	21.3	21.5	22.0
796	20.8	19.0	21.3	17.0	21.4	20.3	22.2	18.2	21.7	16.5
800	24.3*	15.6	17.0*	16.6	18.5*	19.0	17.9*	20.1	18.2*	21.2
804	21.3	21.1	20.9	17.2	21.4	23.7	20.1	19.9	21.0	15.9
808	20.6	20.7	21.1[1]	20.5	20.5	19.2	20.7	20.4	21.2	18.1
820	19.4	16.7	19.2	21.5	20.1	21.5	20.0	20.1	20.5	20.9
826	20.8	21.0	19.9	19.8	21.2	21.1	20.1	21.3	15.8	17.5
832	20.2	17.8	20.1	21.0	21.4	21.0	20.2	21.2	20.5	21.4

Profiles where a 1.300 g/cm³ density was not reached are marked with the greatest density measured as follows: *1.250 g/cm³, [1]1.290 g/cm³.

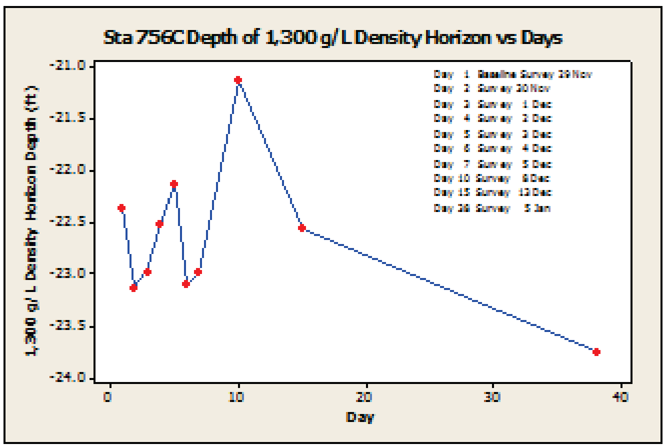
Table A-1. (concluded)

Station	12/4/2011		12/5/2011		12/8/2011		12/13/2011		1/5/2011	
	Den	YS	Den	YS	Den	YS	Den	YS	Den	YS
756	23.1	23.8	23.0	23.0	21.1	15.8	22.6	21.3	23.7	17.1
762	22.3	23.0	23.0	23.0	21.7	20.9	22.4	22.6	21.5	21.7
768	22.4	22.4	18.4*	17.0	17.5*	16.7	19.2*	22.0	17.9*	21.7
780	22.0	22.1	21.2	18.7	20.8	23.0	21.4	22.0	17.7	17.6
784	21.4	19.3	21.8	21.4	21.6	21.8	21.1	21.2	20.8	20.9
788	22.2	22.4	22.5	18.4	21.6	19.6	22.1	21.5	24.6	18.0
792	22.0	22.2	21.2	18.7	21.4	22.4	21.7	21.8	21.9	18.2
796	23.8	20.2	22.1	16.5	15.7	18.0	21.6	22.4	21.8	21.9
800	19.5*	22.9	16.6*	21.5	24.0*	17.8	18.9*	22.2	16.7*	21.5
804	25.0	17.1	21.4	19.0	20.8	20.6	27.0	17.9	19.0	18.6
808	21.1	21.1	21.5	21.3	22.0	17.1	21.3	20.8	19.2	20.7
820	21.5	22.9	21.7	18.0	20.8	20.6	20.4	21.6	20.0^2	21.7
826	20.9	18.8	20.5	22.0	22.1	21.4	21.0	21.1	20.3	16.3
832	19.9	20.2	23.0	18.5	21.0	19.0	20.4	19.7	19.5	19.2

Profiles where a 1.300 g/cm^3 density was not reached are marked with the greatest density measured as follows: *1.250 g/cm^3, ^{2}1.278 g/cm^3.

Appendix B: Station Density vs. Days Plots

Appendix B displays 1.300 g/cm3 density depths vs. time (days), with bedleveler completion day and depth extent indicated by rectangles. The cross-hatched vertical rectangle on these plots illustrates the day that the bedleveler completed the respective pass (from Table 1), and its vertical dimension (3 ft) illustrates the bedleveler's depth extent in relation to the depths at which 1.300 g/cm3 was measured.



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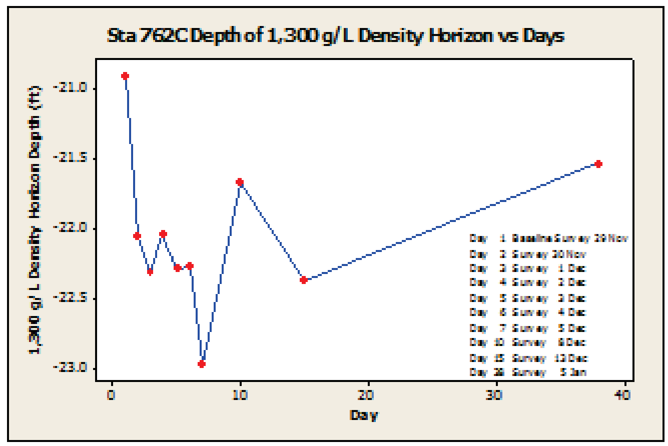

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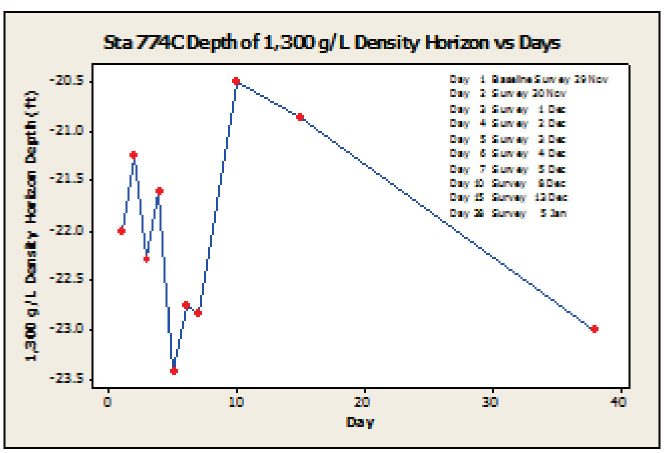

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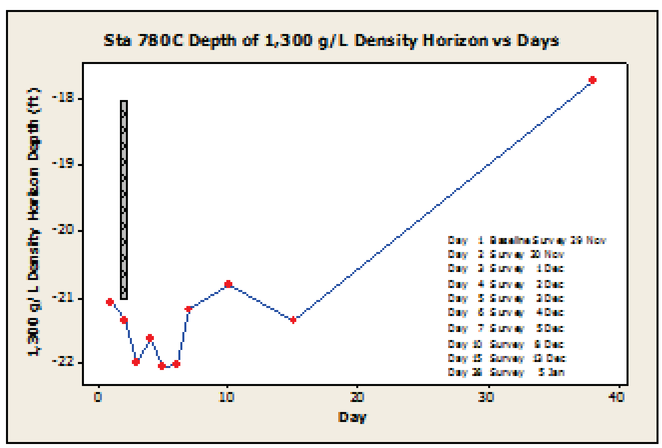

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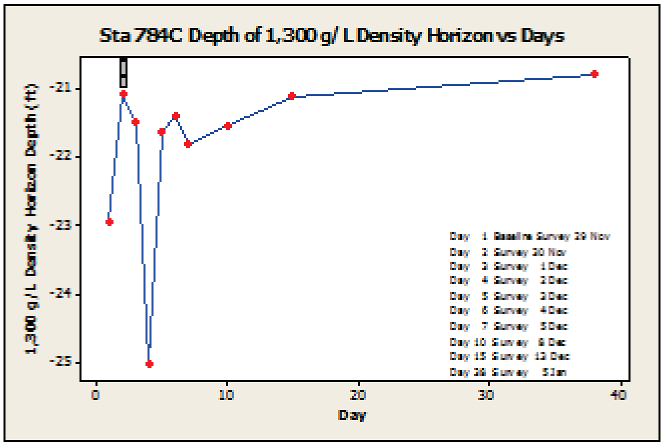

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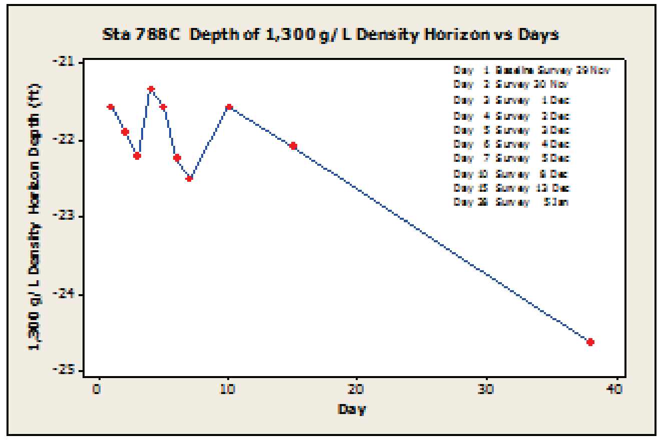

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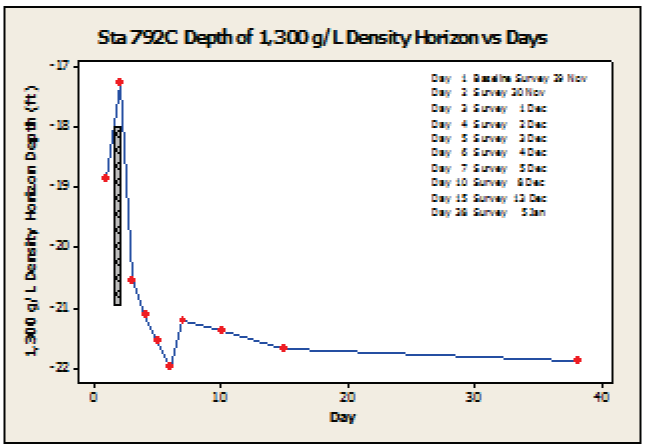

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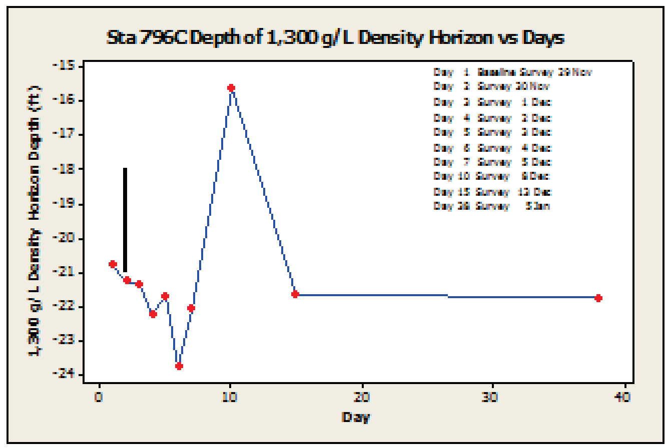

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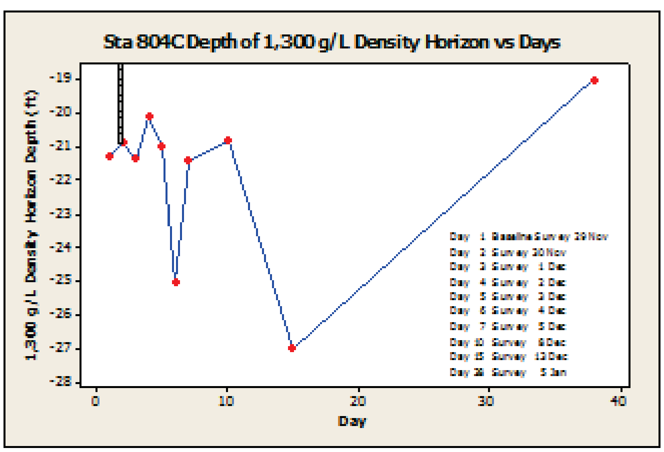

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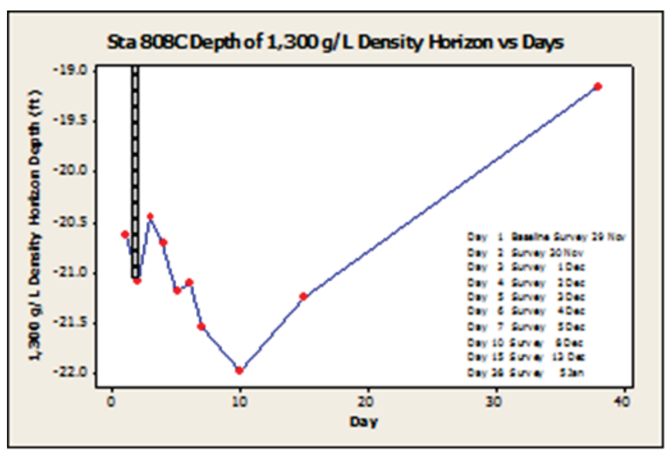

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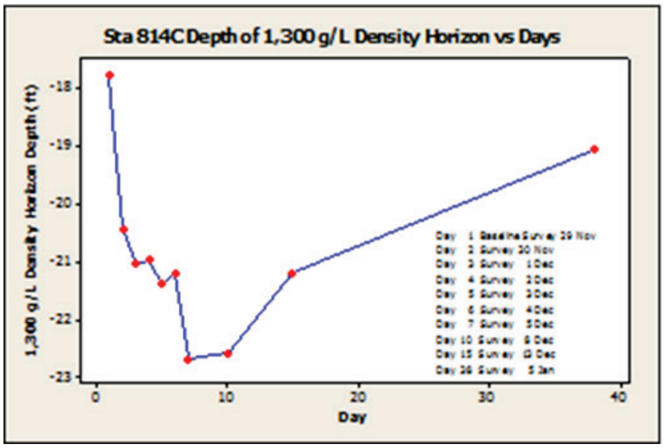

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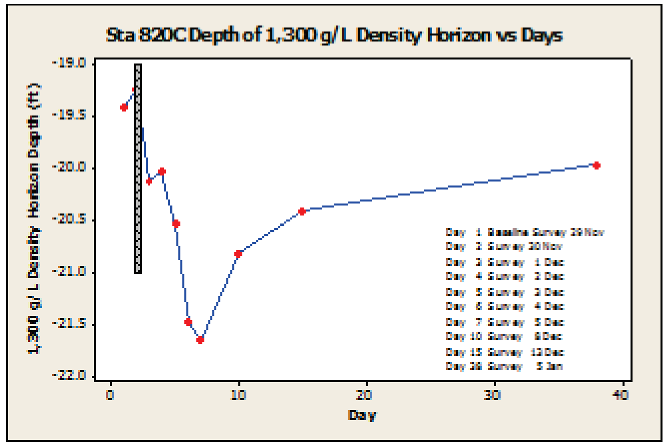

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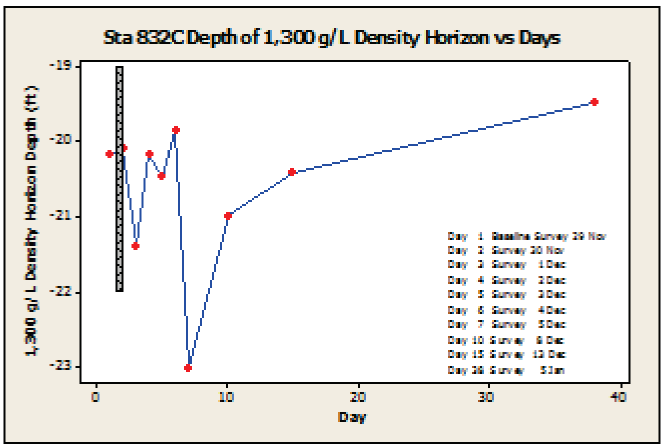

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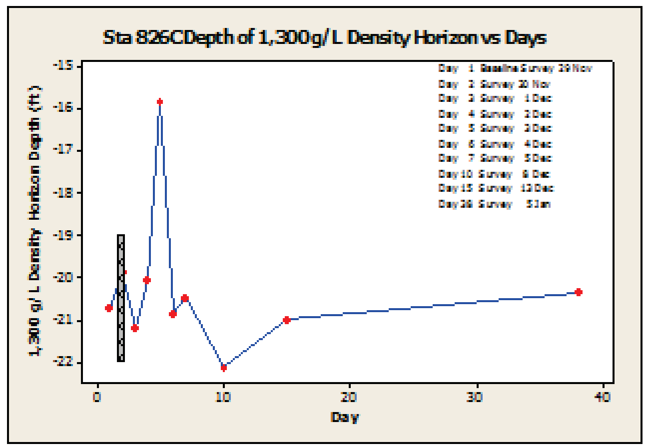
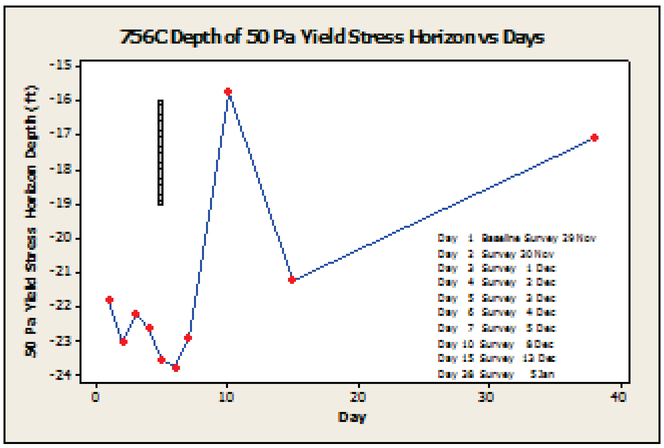


Station 832C

Appendix C: Station Yield Stress vs. Days Plots

Appendix C displays 50 Pa yield stress depths vs. time (days) with bedleveler completion day and depth extent indicated by rectangles. The crosshatched vertical rectangle on these plots illustrates the day that the bedleveler completed the respective pass (from Table 1), and its vertical dimension (3 ft) illustrates the bedleveler's depth extent in relation to the depths at which 50 Pa was measured.



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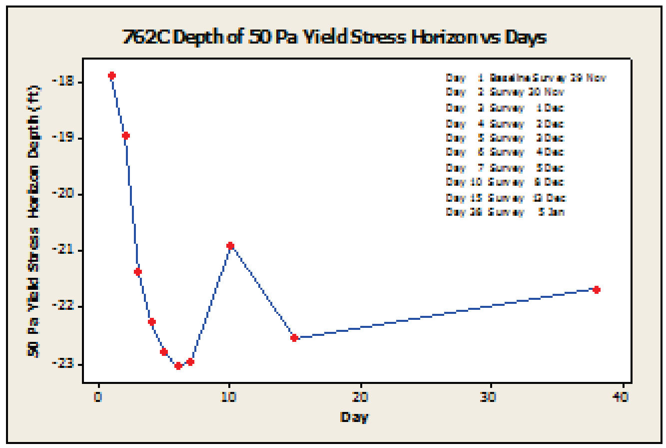

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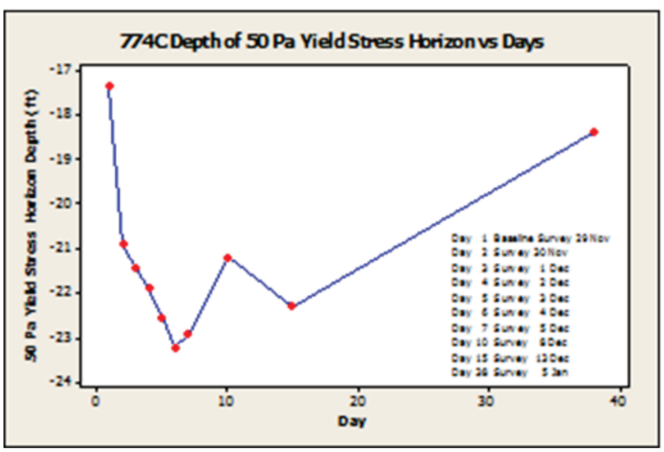

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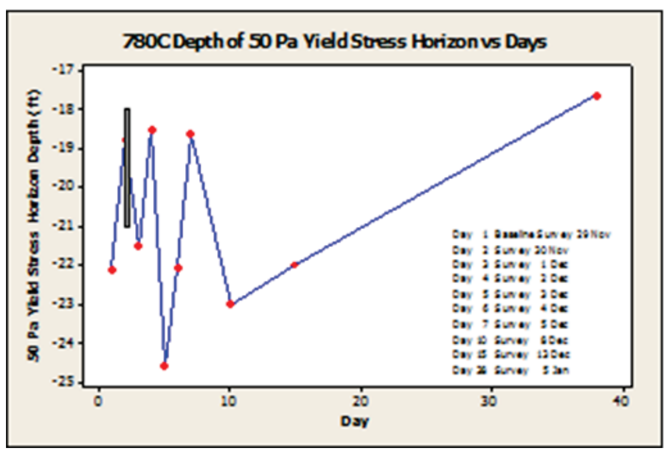

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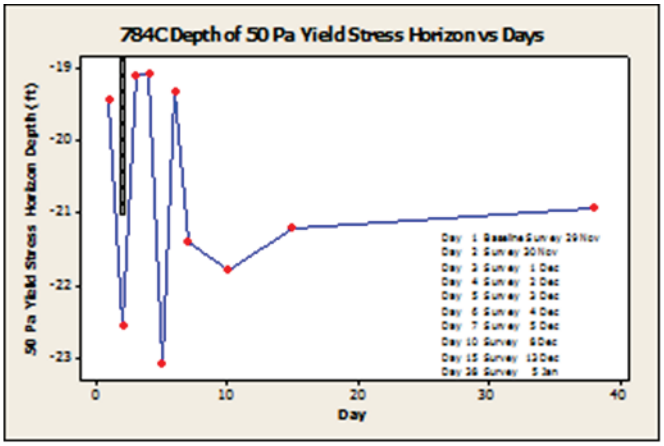

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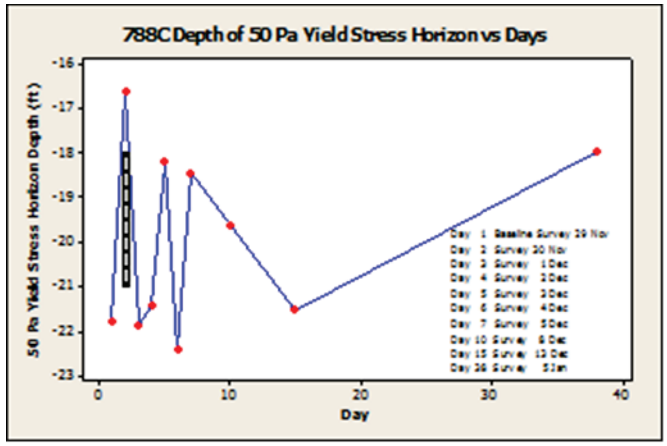

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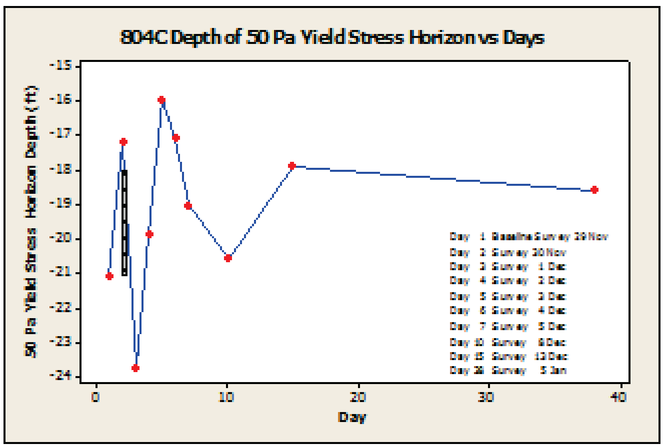

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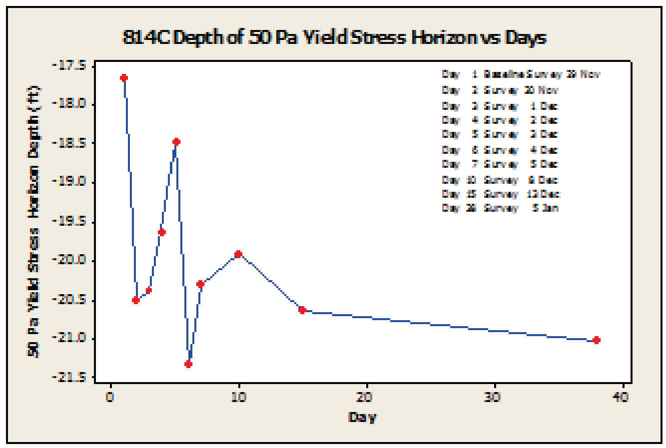

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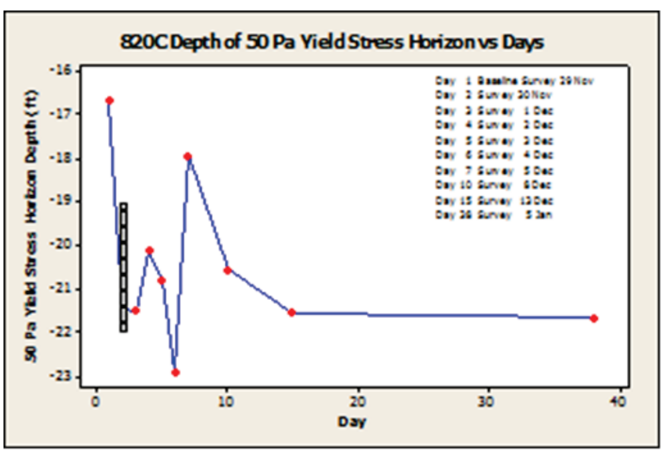

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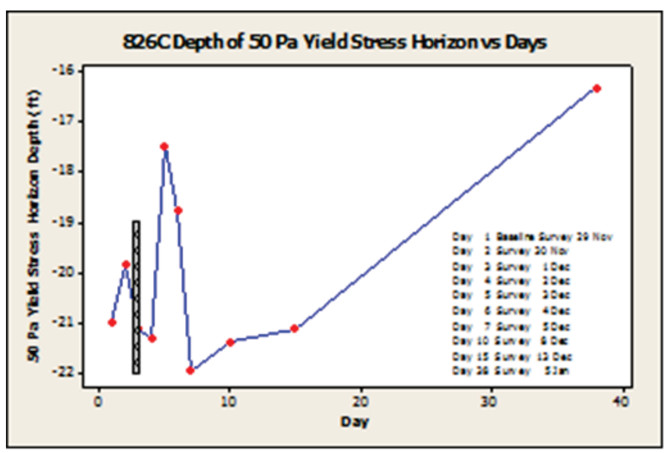

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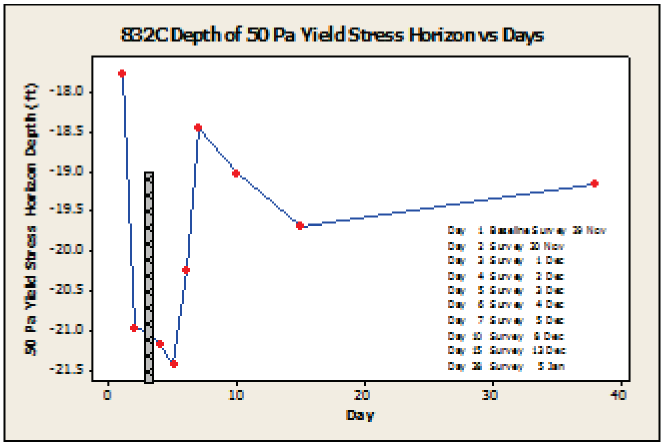

Station 832C

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14. ABSTRACT

Between routine navigation dredging operations, the Atchafalaya River Bar Channel (ABC) traps fluid mud, which begins to consolidate. The consolidated mud can begin to block the passage of vessels using the Port of Morgan City, LA. If the mud densities and yield stresses could be kept sufficiently low so that vessels could safely navigate through it, the length of time between navigation dredging could potentially be increased. To demonstrate the feasibility of dragging a large object through the mud to condition the sediments, a bedleveler was constructed and suspended below a barge at depths that penetrated the interface between the water and the fluid mud in the channel (i.e., the lutocline). The barge was towed along the ABC parallel to its axis, thereby dragging the bedleveler through the fluid mud on the channel bottom.

It was found that dragging the bedleveler along the channel seemed to have no effect, or an extremely limited effect, over a short duration on the densities. It cannot be ruled out that the bedleveler operations had an effect on yield stresses, but the measured decreases were so inconsistent that naturally occurring changes or other factors had a larger effect.

15. SUBJECT TERMS

Atchafalaya River (La.), Barges, Bed leveler, Channels (Hydraulic engineering), Deep draft vessel, Dredging, Fluid mud, Hydrographic surveying, Mud—Density—Measurement, Nautical depth, Nautical bottom, Navigation, River sediment, Sediment conditioning

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